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MEDICAL ELECTRICITY

A
PRACTICAL HANDBOOK
FOR
STUDENTS AND PRACTITIONERS

BY
W. E. STEAVENSON, M.D.
LATE IN CHARGE OF THE ELECTRICAL DEPARTMENT IN ST. BARTHOLOMEW'S HOSPITAL

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PREFACE.

THE materials which had been collected for this book by Dr. W. E. Steavenson, were handed to me by his widow in July last, with the request that I should complete it for publication.

On careful examination of the manuscript it was found that but little of it was sufficiently advanced for the Printer, and a large part of the remainder consisted of brief notes and fragments which could be of little use in new hands, the result being that much of Dr. Steavenson's long and valuable experience in electrical treatment has unfortunately been lost. The plan of the book, however, was clearly sketched out, and has been followed with but little modification. Chapters I., IV., X., and parts of VIII., XIV. and XV., are from Dr. Steavenson's pen.

With regard to Chapters II. and III., which deal with theoretical matters, it was judged to be advisable to rewrite and bring them up to date, and I take this opportunity of expressing my warmest thanks to Mr. H. M. Elder, M.A., for the great assistance given to me in this part of the book.

It may be thought by some that the physical part of the subject might have been better studied in the non-medical textbooks on Electricity, but it was decided to try to bring together into the volume all those parts of the subject which are essential to a rational grasp of the principles which underlie the medical applications of electricity. It is to be hoped that some of those who read the first few chapters of this book may be induced to go further into the study of electricity, and I have tried to indicate the textbooks which might with most advantage be consulted. One thing is certain, that without a thorough grounding in the physical part of the subject, no satisfactory advances can be made in a field of therapeutics which is at present almost entirely neglected by medical men. A great deal of the quackery which surrounds and discredits medical electricity, is due to the indifference and contemptuous attitude of the medical profession, and we have only ourselves to blame if the public insist on seeking elsewhere for treatment which is refused to them by their medical advisers.

Without attempting to enumerate all the works on Electricity and Medical Electricity, of which use has been made in preparing this little book, I take the opportunity of acknowledging my especial obligations to the writings of Prof. Sylvanus Thompson, Dr. Oliver Lodge, Prof. Erb, Dr. De Watteville, and Dr. Vivian Poore.

H. LEWIS JONES.

Upper Wimpole Street, W.

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ERRATUM.

On page 282, line 22, *for* 40 milliampères, *read* 25 milliampères.

MEDICAL ELECTRICITY.

CHAPTER I.

HISTORICAL.

Origin of the word Electricity. Dr. Gilbert of Colchester. Early medical writers. First appearance in hospital practice. Faraday and Duchenne. Position of electricity in medicine. Influence of physical conditions on health. Electrical state of living bodies. Magnetism.

1. **Origin of the word electricity.**—The foundations of the modern science of electricity may be considered to have been laid by a medical man, Dr. Gilbert of Colchester, Physician in Ordinary to Queen Elizabeth. In the year 1600 he published his treatise *De Magnete*. A copy of this work is in the library of the Royal College of Physicians of London, and a reprint is now being prepared under the direction of the Gilbert Club. In it he extended to a large number of other substances the ancient observation that rubbed amber attracted light bodies. It seems also that we owe to him the word Electricity, for he called all those substances Electrics, which when rubbed displayed the same attractive power for light bodies as amber (ἤλεκτρον, electrum) does, and soon afterwards the word electricity was introduced to indicate this power considered as a quantity capable of measurement.

2. **Dr. Gilbert of Colchester.**—Dr. Gilbert does not seem to have attempted to apply his knowledge of electricity in any way to medicine, but he will always be remembered as the pioneer who made the first step towards the scientific investigation of what is perhaps the most wonderful agent that modern science has rendered obedient to the will of man. Dryden has immortalised him in the following lines:—

> "Gilbert shall live till lodestones cease to draw
> And British fleets the boundless ocean awe."*

Another tradition connected with electricity which may be worthy of mention for its interest to the medical profession, is that a *Mr. Davy*, who recently died in Australia, is said to have transmitted a message by means of a wire from one part of St. Bartholomew's Hospital to another, at the time when he was Honse Surgeon there, long before the time of the invention of the Electric Telegraph.

3. **Early medical writers.**—It was more than a hundred years after Gilbert's time that electricity was first brought into use as a curative agent. *Jallabert* in France, and *De Haen* in Germany, were among the first to employ it, in the early part of the last century. In this country it chiefly remained in the hands of non-professional men, but *John Freke*, F.R.S., Surgeon to St. Bartholomew's Hospital, wrote on it in 1702.†

In 1759 the famous divine, the *Rev. John Wesley*, collected most of the recorded cases in which electricity had been used, and published them in a treatise entitled *The Desideratum, or Electricity made Plain and Useful, By a*

---

* Epistle to Dr. Charleton.

† *Freke* carved the chandelier in the Steward's Office at St. Bartholomew's Hospital.

Lover of Mankind and Common Sense.[*] In this treatise *Wesley* mentions *Freke.*

4. **First appearance in London Hospitals.**—The first records of electrical treatment at a London hospital seem to have been in the year 1767, when an electrical apparatus was ordered for the Middlesex Hospital.[†] And ten years later, in 1777, an electrical machine was purchased for the use of the patients in St. Bartholomew's Hospital. According to *Dr. Church's* interesting article in Vol. xxii. of the St. Bartholomew's Hospital Reports on *Our Hospital Pharmacopœia*, it would appear that in 1818 "the electrical machine—whether the original one purchased in 1777 or not, I know not—being out of order, was placed under the care of the apothecary, who was directed to employ *Mr. Blunt*, of Cornhill, when it needed repair. Whether *Mr. Blunt* declined, or was unable to repair the machine, does not appear, but in the following year *Mr. Latchford's* report is entered in the minutes:—

"That the electrical machine at present in use was quite unfit to be repaired. It was proposed by him to make a new machine upon the modern principle, with a plate two feet in diameter, and all the apparatus and case complete to the satisfaction of the medical officers, and afterwards to keep the whole in good and constant repair for a sum not exceeding £17 18*s*., and that the machine be afterwards placed under the care of *Mr. Latchford*, but not to be taken out of the Hospital, and that *Mr. Latchford* will attend and electrify all the patients denoted by the medical officers to undergo the operation upon the following terms: if the operations within the Hospital do not exceed thirty, at 2*s.* each, and if above that number, 1*s.* each. Resolved that the above conditions are approved of, and that the same be carried into effect without delay."

---

[*] This treatise was republished by Messrs. Baillière, Tindall & Cox, London, 1871.

[†] History of Middlesex Hospital, Erasmus Wilson, Churchill, 1845, p. 225.

"How long *Mr. Latchford* performed those duties, and whether he had a successor, I have been unable to find out. In 1838 he petitions for the second time that he should be paid by salary instead of the above terms. No answer to this petition occurs on the minutes, and no further mention of *Mr. Latchford* is found.

"In November 1843 *Mrs. Woodcock's* bequest of £200 consols to the Electrical Institution in Bunhill Row was made over by the executor of her will to the Hospital, as the institution to which she had bequeathed this sum had been dissolved during her lifetime. We see here the dawn of our present admirably arranged Electrical Department, which, however, took upwards of sixty years to blossom into its present perfection."

Electrical departments have at different times been established in connection with other London hospitals. One of the oldest is that of Guy's Hospital. Long lists of cases were published in the "Guy's Hospital Reports" by *Addison*,* *Golding Bird*,† and *Sir William Gull*,‡ in which the use of frictional electricity was followed by most satisfactory results.

Among the first (if not actually the first) treatise published by an English medical man upon the employment of electricity in medicine, was written in Latin by *Dr. Robert Steavenson*,§ of Newcastle-on-Tyne, for some years physician to the infirmary in that town, and great uncle to the present writer.

---

* Guy's Hospital Reports, 1837, no. 2.

† *Ibid.*, vol. vi., 1841. ‡ *Ibid.*, 2nd series, vol. viii., 1852-53.

§ "Dissertatio Medica Inauguralis, de Electricitate et Operatione ejus in Morbis Curandis," *Robertus Steavenson, A. M. Britannus*, Edinburgi, MDCCLXXVIII.

5. **Faraday and Duchenne.**—In 1831 *Faraday* made his discoveries of electromagnetic induction, and began the publication of that splendid series of researches which more than anything else have led to our present state of knowledge of the subject. They have made the applications of electricity a necessity of our civilisation. We must notice *Faraday* particularly here, since from his researches sprang the induction coil or *Ruhmkorff* coil, which is used in the production of the so-called *Faradic* or interrupted currents so much employed in medicine.

The great apostle of faradism was *Duchenne*, of Boulogne, and to him we owe the enunciation of the truth that for curative effects it is necessary that the currents should be localised, that is, applied directly to the parts which it is wished to influence ; *Duchenne* also showed that the muscles could be more easily excited at certain points of the surface, which he called *points d'election*. These have since been proved by *R. Remak* and *Von Ziemssen* to be the places nearest to which the motor nerves enter the muscles, and they are therefore the points at which the nerves can be most easily reached by the current. They are now called "the motor points" (Chap. VIII.).

About 1850 great advances were made in our knowledge of electro-physiology. *Du Bois Reymond* and *Pflüger* demonstrated the electrical phenomena of living nerve and muscle, and established the laws of electrotonus and of muscular contractions, and the existence of muscle currents. *Remak* discovered the catalytic effects of the galvanic current and its influence on osmosis. Our present mode of application of electricity as an aid to diagnosis, has resulted from the investigations of *Brenner*, *Erb*, *Von Ziemssen*, *Althaus*, *Russell Reynolds*, *De Watteville*, *Hughes Bennett*, and many others of note.

6. **Position of electricity in medicine.**—The employment of electricity in medicine has passed through many vicissitudes, being at one time recognised and employed at the hospitals, and then again being neglected and left for the most part in the hands of charlatans and quacks. As each fresh important discovery in electrical science has been reached, men's minds have been turned anew to the subject, and interest in its therapeutic properties has been stimulated. Then after extravagant hopes and promises of cure, there have followed failures and disappointments, which have thrown the employment of this agent into disrepute, to be again, after a time, revived and brought into popular favour. During the long period of two hundred years in which these alterations have been taking place in the opinions held of the value of electrical treatment, and in the frequency of its employment, scientific men have been steadily pursuing their investigations into its wonderful properties and possibilities. Discovery on discovery has rewarded their patience, and we have now arrived at an age when the practical applications of electricity are making the most rapid strides. Medical thought and experiment are moving in the same direction, and another wave of electro-therapeutics is passing over the profession. During the last ten years electrical departments have been reorganised at several of our hospitals, and the powers of electricity have been more and more called in to the aid of the physician and surgeon in their battle with disease. A general desire has been evinced both by members of the profession and by the public, for a more thorough

knowledge of the benefits to be derived from this agent and of the best means of securing them.

7. **Influence of physical conditions on health.**—All physicians recognise the influence exerted upon health and disease by heat, light, and motion in the form of exercise, but very little attention has been paid to the place which electricity occupies in regulating the action of the vital processes. No doubt it has an influence upon the maintenance of health and the production of disease. We have now more accurate means of measuring electricity, and a more perfect knowledge of its action, and although much has still to be learnt under this head, we are altogether in a far better position for employing its effects in the treatment of disease.

We have of late years begun to recognise the influence of physical phenomena upon the conditions of health and disease. We know that the humidity of a locality as affected by the subsoil drainage, has a great influence upon the prevalence of phthisis; that the barometric pressure influences the blood pressure; that electrical changes in the atmosphere, as on the approach of a thunderstorm, strongly influence many persons possessed of delicately strung nerves; that sound, in the form of music, has also an influence upon the system, perhaps through the vaso-motor nerves, though how this effect of music is produced we do not at present understand. We are told that the varying vibrations of the ether by which light of different colours is produced are of use in the treatment of the insane. How these several influences act we are not as yet able to explain. The difference produced in highly sensitive or nervous people by sudden and marked changes in the weather, especially by the sudden changes of temperature to which our climate is so liable, may be partly due to the electrical changes set up thereby.

It is a well known and recognised fact that a few hot days in succession so change the electrical condition of the surface of the earth that a thunderstorm is often necessary to restore equilibrium. It is impossible for human beings to remain at a position of zero with regard to electrical potential, when the potential of every object around is varying. Induction alone would produce electrical separation. It is perhaps fortunate for us that we live in a region where the atmosphere is so charged with moisture that the varying electrical conditions can be more easily equalised. If such sudden changes of temperature took place in countries with a dry atmosphere, the inhabitants might suffer considerably. In those parts of the earth where the air is very dry the recorded manifestations of electrical phenomena accidentally produced on living bodies are almost incredible to the inhabitants of these islands. Rubbing the feet a few times on the carpet will enable an inhabitant of some of the American States, or of the higher Alps, to light a gas jet with the spark which will pass when he presents his finger to the metal point of a gas burner; and electrical displays are produced by combing the hair, which a moist atmosphere seldom allows us to perceive in this country.

There are reasons for believing that the electrical conditions of the atmosphere influence health. This much at least seems to be certain, that differences in the electrical condition of the earth take place, and are continually taking place, and that a highly sensitive organism, such as the human body, must participate and take cognisance of these changes; it is not then too much to suppose that these changes have some influence upon health.

All conditions of the atmosphere which have been noticed to influence health prejudicially, are said to be accompanied by an increase in the amount of the negative electrification of the atmosphere, as indicated by an electrometer. Before a thunderstorm, when people of a delicate nervous temperament assert that they feel indescribable "malaise" and oppression, the atmosphere in the neighbourhood of the earth is negatively electrified.

The predominance of positive electrification of the atmosphere in foggy weather has been assigned as a cause for the immunity then experienced from attacks of pure spasmodic asthma, although the ordinary dyspnœa accompanying bronchitis and emphysema, is often increased at such times.

When we consider that every vital process is most probably accompanied by the production of free electricity in our bodies, that the incidence of every ray of light upon the retina,* our every act of thought, and certainly our every muscular movement have been proved to produce electrical currents, it is improbable that the varying electrical conditions of the atmosphere can take place without influencing our system.

8. **Electrical state of living bodies.**—Although the earth and inanimate objects upon it are usually negatively electrified, human beings in a state of health are almost invariably found to be positive. *Dr. Poore* in his work on "Electricity in Medicine and Surgery" says: "it is remarkable that hardly any two persons are in the same condition electrically, and nervous irritable people are said to exhibit a more active electrical condition than persons of a phlegmatic temperament." *Dr.*

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* *Prof. McKendrick* on "Animal Electricity," before the British Association for the Advancement of Science, September, 1883.

Golding Bird in his lectures before the Royal College of Physicians, in 1847, attributed this existence of free electricity in the human body chiefly to evaporation and respiration, and he sums up his observations on this point under the three following heads. That electricity exists in the human body :—

"1. In a state of equilibrium, common to all forms of ponderable matter.

"2. In a state of tension capable of acting on the electrometer, giving to the whole body a generally positive condition, and arising in all probability from the disturbance of the normal electrical equilibrium by the process of evaporation and respiration.

"3. In a state of current, a dynamic condition, arising from the disturbance of equilibrium by the union of carbon with oxygen in the capillary system, and from other chemical processes going on in the body; such currents, although suspected to be everywhere existing, having been actually detected between the skin and mucous membrane; the stomach and liver, and the interior and exterior of muscular structures."

9. **Magnetism.**—It seems to be rather doubtful whether any physiological effect has ever been observed to be due to the action of a magnet. *Lord Crawford* (then *Lord Lindsay*) and *Mr. Cromwell F. Varley*, with the help of an enormous electro-magnet, belonging to the former, were unable to perceive any sensation even on placing their heads between its poles. But in discussing these experiments in an address delivered at the Midland Institute at Birmingham,* in October, 1883, *Sir William Thomson* came to the conclusion that it is just possible that there may be a magnetic sense, and indeed a committee of the Society for Psychical

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* "Nature," vol. xxix., p. 438.

Research,[*] who examined a large number of persons by placing their heads near the poles of an electro-magnet, found three who were sensitive and were able to say when the current was on or off. One of these persons was examined later by *Prof. W. F. Barrett*,[†] who found that when he was suffering from neuralgic pain, it became intensified by the presence of a powerful magnet.

It need hardly be here pointed out that the phenomena of so-called "animal magnetism" have absolutely nothing to do with magnetism whatever.

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[*] "Proc. Soc. Psychical Research," part iii.

[†] "Nature," vol. xxix., p. 476.

CHAPTER II.

ELECTRICITY AT REST, ELECTRO-STATICS, STATICAL ELECTRICITY.

Division of the Subject. Fundamental Experiments. Hypotheses of Fluids. Electrics and Non-Electrics. Simple Electrical Machine. Electroscopes. Induction. Conduction. Electrophorus. Electric Quantity. Unit of Quantity. Law of Inverse Squares. Electro-motive Force. Potential. Equi-potential Surfaces. Physical Analogies. Definition of Potential. Electrometers. Distribution of the Charge. Electric Density. Action of Points. Capacity. Capacity of a Sphere. Condensers. Dielectric constant. Leyden Jar. Strain in the Dielectric. Lines of Induction and Equi-potential Surfaces. Electric Displacement. Practical Note on Care of Instruments.

10. **Division of the subject.** It is usual for medical men to speak of electrical effects as if they were due to no less than three distinct kinds of Electricity. These we are accustomed to call "Frictional Electricity," "the Continuous Current" and "the Faradic or Interrupted Current." This division, however convenient it may be for purposes of medical treatment, has not even convenience to recommend it when the subject is looked at from a scientific point of view, and is certainly most incorrect. The Science of Electricity may best be divided into four branches as suggested by *Dr. Oliver J. Lodge* in his interesting book "Modern Views of Electricity," a book which should be read with great care by everyone who wishes to have definite and correct notions concerning the science. These four divisions are:—

a. Electricity at Rest, or Static Electricity.—This branch coincides with that portion of the science generally treated of as "Frictional" Electricity.

b. Electricity in Locomotion, or Current Electricity.—This includes the consideration of the continous current and of the faradic or interrupted current.

c. Electricity in Rotation or Magnetism.

d. Electricity in Vibration or Radiation, a branch of the subject treated of in general under the heading of Light.

We only need to consider at all fully the two first of these branches, and of these more especially the second. The fourth branch we need not consider at all, while we shall have to make a few remarks about magnetism in order to make clear the nature and principles of certain electrical measuring instruments.

We will, as is usual begin by first considering Electricity at Rest.

11. **Fundamental Experiments.**[*]—If a piece of glass and a piece of resin be taken they neither attract each other nor any light bodies to which they may be presented. If now they be rubbed together, so long as they are not separated, they still display no powers of attracting light bodies, but let them be separated and they are at once seen to be endowed with the power of attracting each other, and each is capable of attracting light bodies. They are said to be electrified. If a second pair of pieces of resin and glass be taken, rubbed together and then separated, it may be seen—

a. That the two pieces of glass repel each other.

b. That each piece of glass attracts each piece of resin.

c. That the two pieces of resin repel each other.

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[*] "On the Mathematical Theory of Electricity in Equilibrium." *Sir W. Thomson's* papers on "Electro-Statics and Magnetism," p. 43. *Maxwell's* "Electricity and Magnetism," vol. i., p. 31.

The two pieces of glass are said to be oppositely electrified to the two pieces of resin and we can observe as a definition that similarly electrified bodies repel each other, oppositely electrified bodies attract each other. These electrifications are known as *vitreous* or *positive* and *resinous* or *negative.* We also observe that since the rubbed glass and resin before being separated exhibited no powers of attraction or repulsion on external bodies the amount of electrification produced on the glass exactly neutralises the effect of, and therefore is equal and opposite to that produced on the resin.

It should here be noticed that an electrified body exerts no force on any non-electrified body, but that when it appears to do so as in the case in which rubbed glass or resin was seen to attract light bodies the electrified rubbed substance first acts on the neutral bodies and electrically excites them by its influence (*see* § 16), so that the attraction shown is not an action between an electrified body and neutral matter, but between two electrified bodies.

12. **Hypotheses of Fluids.**—Various hypotheses have been put forward to account for this action, all of which more or less fail to do so; two of these may, however, be noticed, more especially as if cautiously used, they supply a convenient means of clearly expressing electrical facts, though it must always be carefully remembered that in using these modes of expression we are making no assumptions as to the truth or the reverse of the hypothesis, but merely using a convenient analogy. The first is the "two fluid" theory of *Symmer.* It is assumed that all matter contains an inexhaustible supply of a so-called electrical fluid which is capable of being split up by friction or otherwise into equal quantities of two fluids of opposite

properties, viz., the so-called vitreous (positive) and resinous (negative) electricities, and bodies that display the properties that we have said are signs of electrification, are said to be charged with a certain quantity of one or other of these fluids, a certain quantity of positive or negative electricity. This hypothesis gives us in many cases a convenient method of expressing the facts, provided always that it be used as such and is not pushed to the point of considering that the electric fluids are any real entities or have any actual existence. It is obvious that it is an essential part of the hypothesis that both fluids shall always be produced in equal quantities.

In the "one fluid" theory which was favoured by *Franklin*, bodies that were positively electrified were looked upon as containing an excess of the electric fluid, bodies that were negatively electrified were looked upon as suffering from a deficiency, while all bodies in the normal neutral state were looked upon as having neither an excess nor a deficiency. It is obvious that this hypothesis has the same advantages and defects as the other. In the sequel we shall use indiscriminately the language of either hypothesis whenever it is convenient to express any fact in terms of them.*

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* It is necessary perhaps to call attention more plainly to this matter and to point out that it is legitimate for the purposes of argument to use an hypothesis that is known to be false, just so far as it is in accordance with the facts and no further, *e.g.*, there are certain problems in geometrical optics that are capable of easy and correct solution if the corpuscular theory of light is assumed for the time being. They are of course capable of solution without making this assumption, but not nearly so easily, and it is perfectly legitimate to assume this as far as these problems are concerned, since it does not conflict with any of the facts that require to be considered in these particular cases. In like manner it is legitimate to speak of the positive and negative electric fluids for the sake of the help such a mode

A warning of *Prof. Clerk Maxwell's* may be quoted *apropos* of this point.* He says, "and here we may introduce once for all the common phrase, *the electric fluid*, for the purpose of warning our readers against it. It is one of those phrases which, having been at one time used to denote an observed fact, was immediately taken up by the public to connote a whole system of imaginary knowledge. As long as we do not know whether positive electricity, or negative, or both, should be called a substance or the absence of a substance, and as long as we do not know whether the velocity of an electric current is to be measured by hundreds of thousands of miles in a second, or by an hundredth of an inch in an hour, or even whether the current flows from positive to negative, or in the reverse direction we must avoid speaking of the electric fluid."

13. **Electrics and non-electrics.**—All bodies when rubbed with suitable precautions are, to use *Gilbert's* term, *electrics*, or rather we should say, that whenever any two bodies are rubbed together electrical separation occurs, one body becoming positively and the other negatively electrified, although in many cases it is difficult to observe this owing to the escape of the charge by conduction or otherwise, and in fact it is possible to arrange all substances in a list, so that when any pair of them is rubbed together, the body higher in the list is positively electrified, while the other is of course negatively electrified to an equal extent.

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of expression gives us in stating our problems simply and clearly, so long as we remember that we use the expressions as a mere *façon de parler* without any assumption as to the existence of such fluids, and so long as such expressions are not in conflict with the facts we are considering.

* "Elementary Treatise on Electricity," p. 8.

Such a list is as follows:—Cat's fur, polished glass, flannel, leather, wood, paper, silk, shellac. Thus:—Glass rubbed with cat's fur will be negatively or resinously electrified, while the same glass rubbed with silk will be positively electrified.

14. **Simple electrical machines.**—Any instrument by which electrical separation is produced may be called an electrical machine. For simple experiments, a glass rod which is rubbed with a piece of silk on which has been smeared some electrical amalgam* is such a machine. Some more elaborate electrical machines will be fully described in a future chapter.

15. **Electroscopes.**—Before going any further it is necessary to consider some means by which we may tell when a body is electrified. Instruments for this purpose are called electroscopes, or sometimes more loosely electrometers. The simplest and best form of electroscope is that known as the gold leaf electroscope, which is made of two strips of gold leaf hung together from a wire. When these are electrified they repel each other and so indicate the presence of electrification. Generally the electroscope is supported in a closed glass vessel containing some strong sulphuric acid to ensure that it shall be dry, and it is in metallic connexion with a disc or plate on the outside of the vessel to which the charges may be given.

It is easy with this instrument to discern the sign of the charge on any electrified body, for if a portion of the charge be transferred to the electroscope and an additional charge be added from a vitreously electrified body, *e.g.*, from a glass rod that has been rubbed with silk, then if the former charge was negative the leaves will collapse, but if positive they will diverge still further.

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* Electrical amalgam is made of tin, one part, zinc, two parts, and mercury, six parts. (*Tyndall's* "Lessons in Electricity," p. 7).

The best way of carrying out this test is as follows:—Approach the charged body to be tested to the electroscope. The leaves will diverge. Touch the plate of the electroscope with the finger for an instant and they will collapse, but on removing the body to be tested, they will again diverge under the effects of a charge of opposite sign to that of the body to be tested. Now bring up near the electroscope a rubbed glass rod, if the leaves collapse the present charge is negative, and that of the original charged body was therefore positive. The reasons for this procedure will be understood from the next paragraph.

In carrying out this test we must be careful not to charge the electroscope too much or the leaves may be torn by the violence of the repulsion.

16. **Induction.***—Take a hollow metal vessel, insulate it by hanging it up by silk threads, and connect it with an electroscope. If the vessel be unelectrified and we introduce into it an electrified body, taking care not to touch the sides of the vessel so that no charge passes from the electrified body to the vessel, the electroscope will indicate a charge, and on being tested it is found to be a charge of the same sign as that on the charged body introduced into the vessel, *e.g.*, if the charged body is a piece of rubbed glass, the electroscope will indicate vitreous or positive electricity. Again, provided the charged body is far enough inside the vessel it may be moved about to any part of the interior, and the charge as indicated by the electroscope remains unaltered. It may even be allowed to touch the inside

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* *Faraday's* Exp. Researches "On Static Electrical Inductive Action." *Maxwell's* "Electricity and Magnetism," vol. i., p. 32.

of the vessel and the electroscope will show no change. If now it be removed without having touched the interior of the vessel, the leaves of the electroscope will collapse, and the vessel will be left without charge, if, however, it has been allowed to touch the vessel, the leaves will remain divergent, but the body will be found to be completely discharged.

In the first case the vessel is said to be electrified by induction, and from the second case we see that the observed induced electrification is exactly equal to, and is of the same sign as that of the inducing body. Had we momentarily connected the vessel to earth so as to discharge the first induced electrification, and then removed the charged body without touching the vessel, the vessel would be found to be charged with the opposite kind of electricity to as great an extent as in the first case. Similar effects are produced whenever an electrified body is brought near any other body, and this is what was referred to in § 11, when it was stated that the light bodies apparently attracted by an electrified glass rod, &c., were first electrified by its influence. In the language of the two fluid theory an electric charge in any body reacts on the neutral fluid in the bodies near it, attracting towards itself an equal quantity of the fluid of opposite sign and setting free an equal quantity of the fluid of similar sign to itself. This is generally illustrated diagrammatically by considering the side of the body nearest to the glass rod as charged with − electricity and the opposite side charged with + electricity, the attraction thus overbalancing the repulsion.

17. **Conduction.**—Let any body, for instance the metal vessel before used, be electrified, taking care that it is supported by silk strings or otherwise insulated.

Let it be connected with another similarly supported non-electrified body by means of a wire for an instant. Now let the second body be examined with the electroscope; it will be found to be electrified in the same sense as the first body but to a less degree; the charge of the first body has been partly *conducted* along the wire connection and has been divided between the two bodies. If connection had been made with a glass rod, a stick of resin, or a silk thread, no transfer of charge would have occurred. The metal wire is therefore a conductor of electricity, the glass rod, &c., are not, they are insulators. This experiment explains why it was necessary to support the charged bodies we have been dealing with by silk threads, it also explains how it was that all the *electrics* known to the ancient electricians were insulators or non-conductors of electricity, since though conductors can be readily excited by rubbing with proper substances, special means must be taken to insulate them that the charge may not leak away before the electrification can be observed.

Substances vary very much in their power of conducting electricity, thus metals are good conductors, water is a fairly good one, the body, wood and cotton are poor conductors, while wool, silk, oils, resins and most kinds of glass are good insulators, sulphur is an almost perfect insulator and dry air is the best insulator known to us.

18. **The Electrophorus**—The principle of electric induction will explain the action of the simplest form of electric induction machine, the electrophorus. It is important to understand this instrument fully as it is the prototype of all the modern so-called "influence machines." In its simplest form the electrophorus consists of a cake of resin, and a disc of metal mounted

on an insulating handle. The resin is first excited by brushing it with a cat skin and the disc is placed upon it by means of the insulating handle. The state of affairs then is as follows:—

The resin being negatively electrified by the friction of the cat's skin (fig. 1) acts inductively on the metal plate across the thin film of air between them (fig. 2). In the language of the two fluid theory, it attracts to

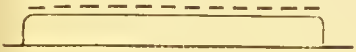

FIG. 1.—The cake of the electrophorus.

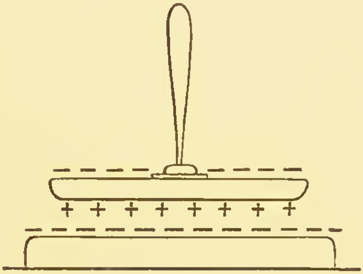

FIG. 2.—The cover applied to the cake.

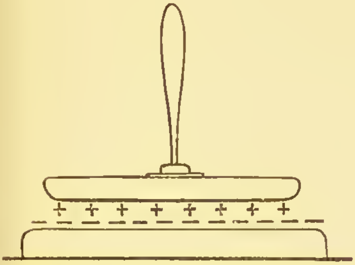

FIG. 3.—The cover after connection for a moment to earth.

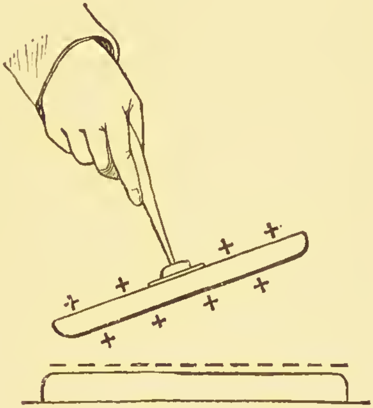

FIG. 4.—The cover raised from the cake, and positively charged.

itself and binds by its influence a positive charge and sets free a negative charge on the upper surface of plate. If the plate is now connected to earth by a touch with the finger, the free negative charge escapes (fig. 3), the positive charge still remaining face to face with the charge of the resin plate. On removing the metal plate by the insulating handle its positive charge is freed from the restraining influence of the inducing negative charge on the resin and may be used to charge any required holder of electricity (fig. 4). This process may be repeated *ad infinitum*.*

The usual form of electrophorus has a metal plate or *sole* under the resin cake, the object of which is to permit a charge to be induced in it that may react inductively with the charge of the resin and so hinder the dissipation of the latter by dust particles, convection, &c. There is generally a pin driven through from the sole to the face of the cake of resin, which dispenses with the necessity of touching the metal plate or carrier with the finger to remove the first induced negative charge.

It is not within the scope of this book to enter more fully into theoretical considerations, but the student may be referred for further information to such books as *Sylvanus P. Thompson's* "Elementary Lessons in Electricity and Magnetism," and *Clerk Maxwell's* "Elementary Treatise on Electricity," and specially, as giving a full popular account of the most modern theories, to the work cited above "Modern Views of Electricity," by *Dr. Lodge.* A very complete account of electric induction and of the electrophorus will be found in Part I., Chapter III., of the last mentioned book.

19. **Electric Quantity.**—Hitherto in this chapter

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* Compare this process with the method of testing by the gold leaf electroscope, § 15.

the consideration of quantity of electricity has been left in the background, and electrification has been spoken of rather as a state or quality super-induced in bodies by certain processes. It is now necessary to arrive at a definite conception of this state as a measurable quantity, *i.e.*, as brought about by the presence of a real or hypothetical something which can be measured and which is called electricity, a something which has been referred to for convenience sake in the language of the "fluid" hypotheses as if it were an actual fluid, but which, it must be borne in mind, is not that, whatever else it may be. Let us suppose the existence of a something which is measurable and which when present in any body endows it with the properties just described under the name of electrification, and which is called Electricity. This electricity then is of two kinds, one named positive or vitreous, and one negative or resinous. It has been seen already that positive electricity repels positive, and that negative repels negative, while positive electricity attracts negative and *vice versâ*. This has to be expressed in terms of some unit, to be chosen once for all.

20. **Unit of Quantity.**[*]—That quantity of electricity, which when supposed collected at a point will repel an equal quantity of similar electricity collected at a point, and placed at unit distance from the first, with unit force shall be taken as the unit quantity of electricity.

Now in this definition the unit quantity of electricity is made to depend on the units of length and of force, and this latter is defined with reference to the units of length, mass and time. Hence the unit quantity of electricity has been completely defined in terms of the units of length, mass and time. For scientific purposes these are taken as one centimetre, one gramme and one second respectively.*

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[*] *Maxwell's* "Electricity and Magnetism," vol. i., p. 44.

There is one matter that has not explicitly been taken into consideration in thus defining the unit quantity of electricity, viz., the medium in which the action between the two charges takes place. It is assumed, however, that this is air.†

Now the attraction or repulsion between two quantities of electricity is proportional to each, *i.e.*, is proportional to the product of the two quantities. It is also inversely proportional to the square of the distance between them, always of course supposing that the two quantities are collected at two points, hence it may be represented by an expression.

$$F = \frac{E\,E'}{R^2}\,K$$

When F stands for the force of attraction or repulsion, E, E′ the two quantities, R the distance between the points at which they are placed, and K some constant depending on the permeability of the medium between them to electric action. But by our definition when E and E′ are equal, and F and R are made equal to unity, E and E′ are to be also unity, therefore we so choose our unit of electrical quantity that K which is called the *specific inductive capacity*, or more correctly the *dielectric constant* of the medium that we are considering, is taken as unity.

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* In the sequel it will be found that all the unit quantities are or can be expressed in terms of the units of length, mass and time, and for scientific purposes these are taken as one centimetre, one gramme and one second respectively. Thus the *unit of velocity* is one centimetre per second, *the unit of acceleration*, one unit of velocity, sometimes called a vel, per second, *i.e.*, a velocity of one centimetre per second added per second. The *unit of force*, is that force which, when acting on a mass of one gramme, gives it unit acceleration, or which when acting on one gramme for one second gives it a velocity of one centimetre per second and is called one dyne. The *electro-static unit of quantity* is that quantity which when placed at one centimeter from an equal and similar quantity repels it with a force of one dyne. This system is called the centimetre-gramme-second system (shortened to C. G. S. system) of units.

† More accurately a vacuum.

The unit quantity of electricity here defined is called the electro-static unit and is used in discussions concerning electricity at rest. It and the other units derived from it lend themselves to calculation from geometrical data, so that for example if the size and shape of a conductor be known it is only a question of mathematics to calculate its electro-static capacity. In discussing electricity in motion we shall use a different system of units based on a different assumption as to the medium concerned. These units are called electro-magnetic units, and many investigations have been made with the object of finding out the relations of the electro-static to the electro-magnetic units.*

21. **Law of Inverse Squares.**—The law referred to in the last paragraph that the force between two quantities of electricity, other things being equal, is inversely proportional to the square of the distance between them, has been proved by direct experiment by *Coulomb* with his torsion balance. A description of this instrument and of the experimental proof is given in all text-books, and for it the student may refer to the above-mentioned "Elementary Lessons in Electricity and Magnetism" by *Prof. S. P. Thompson.* A far more

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* One of the most striking ways in which the connection between electricity and light is shown, is that these relations involve a certain velocity which has been shown by measurement to coincide with the velocity of light.

accurate proof of the truth of the law is given by the famous *Cavendish* experiment, which shows that there is no electric force inside a conductor.*

By an ingenious arrangement of soap bubbles *Prof. C. V. Boys* has lately been able to prove the absence of electric force within a charged conductor, and consequently the law of inverse squares with almost inconceivable accuracy.

22. **Electromotive force, Potential.**†—"Whatever produces or tends to produce a transfer of electrification is called *electromotive force*. Thus when two electrified conductors are connected by a wire, and when electrification is transferred along the wire from one to the other, the tendency to this transfer, which existed before the introduction of the wire, and which, when the wire is introduced, produces this transfer, is called the electromotive force from the one body to the other along the path marked out by the wire."

"To define completely the electromotive force from one point to another, it is necessary in general to specify a particular path from the one point to the other along which the electromotive force is to be reckoned. In many cases, *e.g.*, in electrolytic, thermo-electric and electromagnetic phenomena, the electromotive force from one point to another may be different along different paths; if we restrict our attention, however, as we must do in this part of our subject, to the theory of the equilibrium of electricity at rest, we shall find that the electromotive force from one point to another is the same for all paths drawn in air from the one point to the other."

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* "Electrical Researches of the *Hon. Henry Cavendish*," p. 104, *et. seq.*, p. 417.

† Quoted from *Maxwell's* "Elementary Treatise on Electricity," p. 5.

"The electromotive force from any point along a path drawn in air, to a certain point chosen as a point of reference, is called the *electric potential* at that point. Since electrical phenomena depend only on differences of potential, it is of no consequence what point of reference we assume for the zero of potential, provided that we do not change it during the same series of measurements.

"In mathematical treatises, the point of reference is taken at an infinite distance from the electrified system under consideration. The advantage of this is that the mathematical expression for the potential due to a small electrified body is thus reduced to its simplest form.

"In experimental work it is more convenient to assume as a point of reference some object in metallic connection with the earth, such as any part of the system of metal pipes conveying the gas or water of a town.

"It is often convenient to assume that the walls, floor and ceiling of the room in which the experiments are carried on have conducting power sufficient to reduce the whole outer surface of the room to the same potential. This potential may then be taken for zero. When an instrument is enclosed in a metallic case the potential of the case may be assumed to be zero.

"If the potentials at different points of an uniform conductor are different there will be an electric current from the places of high to the places of low potential. At present we are dealing with cases of electric equilibrium in which there are no currents. Hence in the cases with which we have now to do the potential at every point of the conductor must be the same. This potential is called the potential of the conductor.

23. **Equipotential Surfaces.**—"The region of space

in which the potential is higher than a certain value is divided from the region in which it is lower than this value by a surface called an equipotential or level surface, at every point of which the potential has the given value.

" We may conceive a series of equipotential surfaces to be described, corresponding to a series of potentials in arithmetical order. The potential of any point will then be indicated by its position in the series of equipotential surfaces.

" No two different equipotential surfaces can cut one another for no point can have two different potentials.

24. **Physical Analogies.**—" The idea of electrical potential may be illustrated by comparing it with pressure in the theory of fluids and temperature in the theory of heat. If two vessels containing fluids are put into communication by means of a pipe, fluid will flow from the vessel in which the pressure is greater into that in which it is less till the pressure is equalised. This, however, will not necessarily be the case if one vessel is higher than the other, for gravity has a tendency to make the fluid pass from the higher to the lower vessel. Similarly when two electrified bodies are put into electric communication by means of a wire, electrification will be transferred from the body of higher potential to the body of lower potential, unless there is an electro-motive force tending to urge electricity from one of these bodies to the other, as in the case of zinc and copper. Again if two bodies at different temperatures are placed in thermal communication either by actual contact or by radiation, heat will be transferred from the body at the higher temperature to the body at the lower temperature, till the temperature of the two bodies becomes equalised. The analogy

between temperature and potential must not be assumed to extend to all parts of the phenomena of heat and electricity. Indeed this analogy breaks down altogether when it is applied to those cases in which heat is generated or destroyed. We must also remember that temperature corresponds to a real physical state, whereas potential is a mere mathematical quantity the value of which depends on the point of reference we may choose. To raise a body to a high temperature may melt or volatilize it, to raise a body, together with the vessel which surrounds it, to a high electrical potential produces no physical effect whatever on the body. Hence the only part of the phenomena of electricity and heat which we may regard as analogous is the condition of the transfer of heat or of electricity according as the temperature or the potential is higher in one body or in the other. With respect to the other analogy—that between potential and fluid pressure—we must remember that the only respect in which electricity resembles a fluid is that it is capable of flowing along conductors as a fluid flows in a pipe" (§ 17).

In terms of this analogy the electricity is compared to the fluid, while the pressure of the fluid at any point answers to the potential of the electricity at a corresponding point, the difference of pressure between two points causes the flow of fluid from one to the other while similarly the electro-motive force or difference of potential between two points causes the flow of electricity from one to the other.

The conception of electric potential is a very difficult one, and this is not the proper place for a discussion of it in all its bearings; enough has been said in the long quotation from *Clerk Maxwell* to give some idea of the meaning of the word, but the student who wishes to obtain a thorough insight into it cannot do better than read *Clerk Maxwell's* "Elementary Treatise on Electricity," giving special attention to Chapter III., on "Electrical Work and Energy." In most of what follows and especially in the part which refers to electricity in motion the idea of electric pressure in connection with the word potential will be the dominant one, but it must always be remembered that this idea of pressure is based on the analogy of the electric flow to a fluid flow, and this is at best very imperfect.

25. **Definition of potential.**—It must be noticed here that the definition of potential just given is a very imperfect one. A complete definition is the following:—

The amount of work done against the electrical forces of the system, by an external agent, in carrying one unit of positive electricity from a place where the potential is zero, to a given point, is called the electric potential at that point. This definition includes that just given and is complete. We shall have to recur to this subject in the next chapter.

It is a consequence of this definition that unit difference of potential is the difference of potential between two points when one unit of work is expended in moving unit quantity of positive electricity from the point at lower potential to that at the higher.

Also if E be the quantity of positive electricity at any point, the potential due to this at any other point distant R from it is $\frac{E}{R}$.*

26. **Electrometers.**—The only thing that can be observed in connection with electricity at rest is a difference of potential. It is possible to measure the quantity of electricity driven through certain instru-

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* *Maxwell*, "Elementary Electricity," p. 67.

ments, just in the way that a quantity of water driven through a water meter can be measured, and some of these instruments will be discussed in a future chapter; but for the present we can only appreciate electrical charge by observing a difference of potential, and electroscopes and electrometers are instruments for showing or measuring differences of potential. A quotation from *Dr. Lodge's* "Modern Views" may make this clearer:— "Imagine now that we live immersed in an infinite ocean of incompressible and inexpansible all-permeating perfect liquid, like fish living in the sea; how can we become cognizant of its existence? Not by its weight, for we can remove it from no portion of space to try whether it has weight. We can weigh air, truly, but that is simply because we can compress it and rarefy it. An exhausting or condensing pump of some kind was needed before even air could be weighed or its pressure estimated. But if air had been incompressible and inexpansible, if it had been a vacuumless perfect liquid, pumps would have been useless for the purpose, and we should necessarily be completely ignorant of the weight and pressure of the atmosphere. How then should we become cognizant of its existence? In four ways:—

"*a.* By being able to pump it out of one elastic bag into another (not out of one bucket into another; if you lived at the bottom of the sea you would never think about filling or emptying buckets—the idea would be absurd; but you could fill or empty elastic bags), and by noticing the strain phenomena exhibited by the bags and their tendency to burst when over full.

"*b.* By winds or currents; by watching the effect of moving masses of the fluid as it flows along pipes or through spongy bodies, and by the effects of its inertia and momentum.

"*c.* By making vortices and whirls in the fluid and by observing the mutual action of these vortices, their attractions and repulsions.

"*d.* By setting up undulations in the medium, *i.e.*, by the phenomena which in ordinary media excite in us through our ears the sensation called sound.

"In all these ways we have become acquainted with Electricity, and in no others that I am aware of. They correspond to the four great divisions of the subject which I made above" (see § 10).

The observations then that we are able to make on potential, answer to observing the strains of the elastic bag of *Dr. Lodge's* analogy.

Since electro-motive force is difference of potential, an electrified body tends to move from places of high to places of low potential.

27. The gold leaf electroscope has been shortly described in § 15. The divergence of the leaves of this instrument may be taken as an indication that the knob or disc, which was termed by *Faraday* the *electrode*, or way by which electricity enters the instrument, is at a different potential to the walls of the room, or to that of the metal cage that surrounds some forms of the instrument, but obviously without further observation it does not tell whether the potential is higher or lower, *i.e.*, more positive or more negative, and further tests must be made to discover this. Neither does it give us more than the roughest indication of the amount of difference of potential. In cases where there is a great difference of potential, and a delicate gold leaf electroscope is likely to be spoilt, rougher forms may be used, *e.g.*, Dutch metal or even pith balls suspended by linen threads may be used instead of the more delicate gold leaf.

If it is required to measure a difference of potential an *electrometer* must be used. There are many forms of these, most of which are due to the inventive genius of *Sir W. Thomson.* Descriptions of the various forms will be found in most text-books, such as for instance in *S. P. Thompson's* "Lessons in Electricity and Magnetism," or the article "Electrometer" in the last edition of the "Encyclopædia Britannica," but best of all in *Sir W. Thomson's* papers on "Electro-statics and Magnetism," pp. 263 *et seq.*

28. **Distribution of Charge; Density.**—It has already been observed that the whole of an electric charge resides on the surface of a charged conductor (§ 16), and this has been proved by direct experiment in many ways. We may now proceed to discover if the distribution over a conductor is uniform or not. The experiment is easily tried by testing different parts of a conductor with a small carrier, a disc of conducting material supported on an insulating handle, called a *proof plane*, and it is soon found that while the distribution over a sphere is uniform, as we should expect from the symmetry of the figure, it is not so on conductors of other shapes, but the greater the curvature of the surface, the more electricity is taken up by the proof plane. Let us define the quantity of electricity per unit (square centimetre) of surface as the electric density, then the electric density is the same at all points of a sphere uninfluenced by surrounding objects, but on conductors of other shapes the density is greater the greater the curvature of the surface, till at a sharp edge or a point the density becomes so great that a discharge takes place. For this reason if a point is attached to a charged conductor a stream of charged particles of air is repelled from the point giving rise to a wind setting from the point and rapidly discharging the conductor.

29. **Action of points.**—We must consider this action of points a little more fully, as it becomes of great importance in electrical machines, and sometimes in electrical treatment. In the first place the presence of a point on a charged conductor renders it impossible to keep a charge on the conductor, however well it may be insulated. But the same effect will occur if a point be presented to a charged conductor, for the charge, which we will suppose is positive, of the conductor acting inductively on the point will induce a negative charge at the point, the density of which will become so great that it will be discharged to the original conductor, neutralising its positive charge and leaving the conductor which bears the point positively charged if it is insulated. It is by this means that the prime conductors of most electrical machines are charged from the excited plate or other moveable part.

30. **Capacity.**—The quantity of electricity that is required to raise the potential of any conductor from zero to unity, all other conductors in the neighbourhood being kept at zero potential, is called its *Capacity.*

Hence if a charge E be given to any conductor at zero potential, and its potential is thereby raised to V, if C stand for the capacity—

$$C = \frac{E}{V} \text{ or } E = CV.$$

Hence if we know the capacity of any conductor, and can determine its potential by means of an electrometer, we are able to calculate the quantity of electricity on it.

31. **Capacity of a sphere.**—It is shown in *Maxwell's* "Elementary Treatise" that the capacities of certain conductors may be calculated from their shapes, *e.g.*, that the capacity of a sphere is numerically equal to its

radius, and that the capacity of a sphere of radius a surrounded by a concentric sphere of radius b which is kept at zero potential is given by the expression—

$$\frac{a\,b}{b-a}.$$

That is to say a sphere whose radius is 10 centimeters concentric with one whose radius is 11 centimeters, will have a capacity, if the outer sphere is kept at zero potential, of

$$\frac{10 \times 11}{11 - 10} = 110 \text{ units},$$

whereas such a sphere not surrounded by another sphere but suspended apart from other conductors in space, would only have a capacity of 10 units.

If the radius of the outer sphere were reduced to $10\frac{1}{2}$ cm., the capacity of the inner one would become

$$\frac{10 \times 10\frac{1}{2}}{10\frac{1}{2} - 10} = 210 \text{ units},$$

so that the closer the spheres are the greater the capacity of the inner one.

In general the nearer that uninsulated conducting bodies are to a conductor the greater the capacity of that conductor.

32. **Condensers.**[*]—An apparatus consisting of two insulated conductors, each presenting a large surface to the other, with a small distance between them, is called a condenser, because when one conductor is connected to earth, a small electromotive force is able to charge the other with a much larger quantity of electricity than if it stood alone, *i.e.*, its capacity is increased by the proximity of the other conductor (see § 31).

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[*] *Maxwell's* "Elementary Treatise on Electricity," Chap. VIII.

The simplest form of condenser consists of two metallic discs supported on insulating stems and facing each other, the intervening non-conductor or *dielectric* being air. If now a different dielectric, as for example, a sheet of glass, be inserted instead of air, the capacity of the condenser will be found to be different and greater than before, thus, the induction across the dielectric depends on the nature of the dielectric (cf. § 20).

33. **Dielectric constant.**—Since a glass condenser has a higher capacity than an air condenser, glass transmits induction better than air, and we say that glass has a higher *dielectric constant* or *specific inductive capacity* than air. Now in § 20, in defining our unit quantity of electricity, we assumed the dielectric constant of air to be unity. We now see that we might have assumed that of any other standard substance as unity, but in doing so we should have obtained a different unit of electrical quantity.

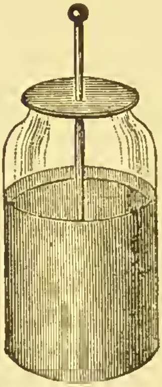

FIG. 5.—Leyden jar.'

34. **Leyden jar.**—The electrical condenser most often used in experiments on static electricity is that known as the Leyden jar (fig. 5).

The ordinary form of this apparatus is a glass jar or bottle, coated inside and out with metal foil to within two or three inches of the top. Through the cork of the bottle a wire passes, terminating above in a knob, and below in a chain to make metallic contact with the inner coating. To charge the jar the outer coating is connected to earth, and so kept at zero potential, while the inner coating is connected with the conductor of an electrical machine or charged by an electrophorus. The charge given to the inner coating acts inductively across the dielectric of the jar, which is thus able to retain its charge. It may be discharged by bringing a metallic conductor, which is in connection with the outer coating, near to the knob of the jar. A spark will occur and the jar is discharged.

35. **Strain in the dielectric.**—There is one experiment that may be performed with a particular kind of Leyden jar that must be noticed. Let us take a jar in which the coatings are removable, connect the outer coating to earth and charge the jar. Then remove the inner coating by an insulating handle and also the outer coating. These may be tested by an electrometer and will show but small sign of charge, they may be completely discharged and put back into place with the same precautions as before. Now on connecting the coatings a spark will pass just as if the coatings had never been removed. The meaning of this is that the electrical effect resides not in the charged bodies but *in the dielectric between them.* In fact we are taught by this experiment to look on static electrical action as a state of strain in the dielectric between conductors, rather than as a state of the conductors themselves. *Faraday* was the first to work out this idea, and he symbolized it by diagrams expressing the state of the dielectric medium.

36. **Lines of induction.**—Let us suppose a charge of say ten units of positive electricity situated on a sphere and uniformly distributed on it. It is essential to the existence of this charge that on surrounding objects at zero potential there shall be a corresponding negative charge of ten units. Let now the surface of the sphere be divided into ten equal parts, and each will contain one unit of electricity, and let lines be drawn, 4π from each part parallel to the direction in which a particle charged with positive electricity would be repelled. These lines are to be continued always parallel to the direction of the electric force at each point till they terminate in the body at zero potential where the corresponding negative charge exists. These lines are called *lines of induction* (or sometimes less aptly "lines of force"), and are perpendicular to the equipotential surfaces referred to in § 23. The whole of the space with which we are concerned, the *electric field* within the conductor at zero potential, is mapped out by these lines of induction and equipotential surfaces, and if the original sphere be replaced by a conductor coinciding in position with any of the equipotential surfaces, the charge at any portion of that surface is given by the number of lines of induction crossing it divided by 4π.

Diagrams will be found in *Clerk Maxwell's* "Electricity and Magnetism," of the lines of induction and equipotential surfaces round points charged in different ways. (*See* also *Dr. Lodge's* "Modern Views," and *Maxwell's* "Elementary Electricity," § 93, *et seq.*).

37. **Electric displacement.**—There is a way of looking at electrification from this point of view of lines of induction, for a more complete exposition of which we may refer to the above mentioned "Modern Views of Electricity," in which the dielectric is considered as

strained by the displacement of electricity all along a line of induction, and as, in virtue of its dielectric properties, elastically opposing this displacement.

38. **Practical note.**—In performing experiments on statical electricity it is essential to remember that dust and damp are great enemies to success. Glass has a great power of condensing a thin film of moisture on its surface, and this film of water has conducting power sufficient to discharge any charged conductor. Hence it is necessary that all the instruments should be absolutely clean and dry, and to effect the latter the most convenient way is to warm them. Another method of minimising the hygroscopic power of glass is to cover it with a shellac varnish. It is well to remember too that there are certain kinds of lead glass that conduct passably well, and consequently will not insulate even when warm and dry. In our climate we need never be surprised at the failure of electro-static experiments, even after the most elaborate care has been expended on them.

CHAPTER III.

Electricity in Motion.

Contact electromotive force. Simple Voltaic cell or battery. Oersted's experiment. Magnetism. North seeking and South seeking poles. Strength of pole. Permeability. Magnetic moment. Magnetic field. Lines of force. Field of force about a wire carrying a current. Unit current. Galvanometers. Tangent and Sine galvanometers. Galvanometer constant. Ammeters and voltmeters. Reflecting galvanometer. Electromotive force. Resistance. Ohm's law. Practical units. Electrolysis. Anode and kathode. Laws of electrolysis. Electro-chemical equivalents. Legal Ohm. Specific resistance. Resistance of an electrolyte. Measurement of resistance. Network of conductors. Shunts. Wheatstone's bridge. Post office box. Arrangement of batteries. Internal resistance. Heating effects. Electromagnetic induction. Lenz's law. Mutual induction. Self induction. Ruhmkorff's coil. Magneto-machine. Dynamos. Practical note.

39. **Contact electromotive force.**—It was observed at the end of the last century by Volta, that when dissimilar metals, such as zinc and copper, were brought into contact in air, electrical separation took place, and a difference of potential was set up between the metals, the zinc being positive to the copper, or at a higher potential.* Under these circumstances this difference of potential does not efface itself by discharging across the junction of the two metals as a difference of potential between two parts of a homogeneous conductor would do. If it could do so there would be a continual flow of

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* A different view is taken by Dr. Lodge, see "Modern Views of Electricity," Chap. VI.

current from zinc to copper, and this would result in the heating of the circuit, and an expenditure of energy or rather in a creation of energy, which is impossible. Again, the electromotive force set up at the junction of the two metals could only discharge itself across the junction by a flow in the opposite direction to that in which it tends to cause a flow, but that is absurd. But if the two pieces of metal while in contact are immersed in some liquid that is capable of acting chemically on one of them, *e.g.*, dilute sulphuric acid, a complete circuit is formed, and the discharge can take place through the liquid, which undergoes decomposition thereby, and the difference of potential being continually renewed, a continuous discharge takes place round the circuit in the following way :—

Positive electricity passes across the junction of copper and zinc, and then from the zinc across the liquid to the copper again. If the connection of copper to zinc be by a wire, as is usually the case, we may use the language of the two fluid hypothesis and look on the junction as a sort of pump driving positive electricity round the circuit, so that it passes from zinc across the liquid or electrolyte to copper and back to the zinc again along the metallic connection between it and the copper, thus making a true circuit.

This theory of a contact electromotive force is not altogether satisfactory, since it fails to explain many facts that are observed, moreover the seat of the supply of energy to the circuit is certainly not at the junction of the copper and zinc, where it should be to accord with the theory. It must therefore be looked on as merely a working hypothesis of the same class as the fluid theory of § 12, until a satisfactory theory is propounded.

40. **Voltaic cell.**—Such an arrangement is called a Voltaic cell, and but for disturbances that will be more fully considered in Chap. V., it would give a continuous current, till either the zinc or the exciting liquid (called the *electrolyte*) was exhausted. The difference of potential in a cell or its *electromotive force* is due to the contact electromotive force of the metals forming the poles of the cell, though in certain cases this may be slightly modified by the liquid used. It is possible to increase the electromotive force by joining together a sufficient number of simple Voltaic cells, zinc of one to copper of the next. Such a combination of cells is called a battery, and the cells are said to be joined *in series*, and the electromotive force of the battery is equal to the sum of the electromotive forces of the cells which compose it.

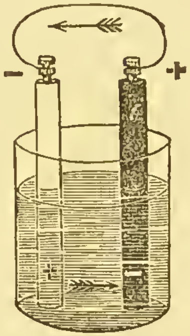

Fig. 6.—Single Voltaic cell showing poles and direction of flow inside and out of cell.

It is customary in some textbooks to speak of the zinc plate of a battery as the positive plate, and the copper or other plate as negative, while the terminal attached to the zinc plate is called the negative pole, and that attached to the copper the positive. The origin of this very confusing nomenclature is no doubt the fact that in the battery the positive direction of flow of the current is from zinc to copper, and that zinc is said to be electro-positive to copper. But in the connecting wire the positive direction of flow of the current is from copper to zinc (see fig. 6), and as this is the portion of the circuit that we are most concerned with, the word positive will be used to denote the positive pole of the battery and also the plate connected with it, when it is necessary to specify this. This is in conformity with the usage of electrical engineers, who speak of the peroxide plates in an accumulator as "positives."

41. **Oersted's experiment.**—Let a small magnet, say a compass needle, be suspended freely at rest. It will point North and South, now over it let there be carried a wire joining the two terminals of a cell or battery in such a way that its course from copper to zinc along the wire shall be from South to North, *i.e.*, so that the current (the positive direction of flow) is from South to North, then the North seeking end of the magnet will be deflected towards the West. This observation is due to Oersted of Copenhagen, and it was formulated by him into .a law for telling the direction of flow in a circuit thus:—Imagine a man swimming with the current in the wire, *i.e.*, from copper to zinc and facing the needle, the North seeking end of the magnet will always be deflected towards his left hand, whatever the position of the wire with regard to the magnetic needle.

42. **Magnetism.**—It will be convenient at this point to make a short digression and discuss the properties of magnets and the laws by which they are governed. We will assume a knowledge of the elementary facts of magnetism, which are somewhat analogous to those of electro-statics, viz., the existence of magnetic poles of two kinds, which occur of equal and opposite strength

in every magnet, and that similar poles repel each other while dissimilar poles attract each other, and we will consider an ideal magnet, say of thin wire, such that its poles are situated at its ends. We may, just as in the case of static electricity, consider these poles as points charged with a hypothetical something which is called magnetism, at the same time being careful to remember that in using this language we are merely representing facts in terms of a convenient metaphor (see § 12).

43. **North seeking and South seeking poles.**—When a magnet is suspended freely at the surface of the earth it is found that it swings so as to set itself with one pole pointing towards the North (or at least approximately so) and the other towards the South. These poles are spoken of as the *North seeking* and *South seeking* poles respectively, and their names are abbreviated into N. and S. for convenience. Magnets are often painted the N. end red and the S. end blue, as suggested by Sir W. Thomson.* For purposes of definition, one magnetic pole only may be considered, although in practice both will always have to be taken into consideration, as it is not possible to deal with infinitely long magnets.

44. **Strength of magnetic pole.**—*Def.* A magnetic pole of such strength that it will repel an equal and similar magnetic pole placed at unit distance (one centimetre) from it with unit force (one dyne†) is called unit

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* These poles are therefore sometimes called red and blue respectively. It is obvious that if the earth be looked on as a magnet, the North pole is affected (charged) with S. magnetism, the South pole with N. Sometimes the N. seeking pole of a magnetic needle is "blued," while the S. seeking pole is left bright.

† Dyne the C.G.S. unit of force. That force which acting on 1 gramme for one second changes its velocity by one centimetre per second.

magnetic pole (cf. § 20). In the language of analogy such a magnetic pole may be said to be charged with unit quantity of magnetism.

The same considerations apply here as in the case of quantities of electricity. The force between two magnetic poles is proportional to the product of their strengths, and inversely proportional to the square of their distances, hence it may be represented by an expression.

$$F=\frac{mm'}{r^2}\mu$$

Where F stands for the force of repulsion or attraction, m, m′ for the strengths of pole, r the distance between them, and μ is some constant depending on the permeability of the medium between them to magnetic action. But by our definition when m m′ are equal, and r and F are made equal to unity, m and m′ are also unity, therefore we must so choose our unit strength of pole that μ, the magnetic permeability of the medium that we are considering, viz., air,* is unity.

This is an important matter as it is the unit upon which our whole system of electro-magnetic units (cf. § 20) is based. As explained there the electro-static units start with the assumption that the dielectric constant of air shall be unity, so the electro-magnetic units are based on the assumption that the magnetic permeability of air shall be unity. Obviously both these assumptions are not necessarily true together, and if they had happened to be so our electro-static and electro-magnetic units would have coincided in magnitude but they do not.

45. **Magnetic moment.**—The product of the strength of one magnetic pole of a magnet into the distance between the poles of the magnet is called the *magnetic moment* of that magnet. This is the measure of the tendency of the magnet to turn about its centre when placed in a magnetic field of force (*see below*) of unit strength.

46. **Magnetic field. Lines of force.**—The re-

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* More correctly a vacuum. But these factors for air as compared with a vacuum, differ very slightly from unity.

gion of space about any magnet and throughout which we consider its action is called its *field*. By a reference to §§ 23 and 36 in which the method of mapping an electric field by means of lines of force and equipotential surfaces was described, we see that we can map a magnetic field in exactly the same way. We can draw a series of equipotential surfaces round a magnet (defining magnetic potential in a similar way to our second and complete definition of electric potential in § 25) and map out the lines of magnetic induction or lines of force with the same convention and in the same way as we did the lines of electro-static induction, cutting the equipotential surfaces at right angles. These will then all start from points or surfaces indued with N magnetism and end in points or surfaces indued with S magnetism and the intensity of a magnetic field at any point will be given by the number of lines of force which cross per square centimeter of surface at right angles to them at that point.

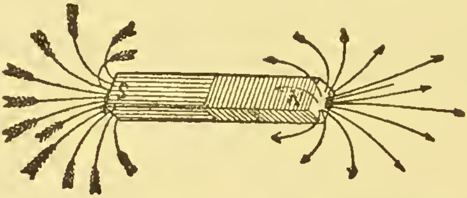

FIG. 7.—Lines of force near the poles of a magnet. The lines should be produced to meet, as they are really continuous circuits.

The force with which unit magnetic pole is urged in the direction of the lines of magnetic induction or the lines of force at any point is called the strength or intensity of the field at that point. If a surface be drawn through the point at right angles to the lines of force there, the number of lines of force per unit area of that surface which cross it, is a measure of the force, *e.g.*, a magnetic field of unit strength will have one line of force per square centimetre and a magnetic pole of unit strength placed in such a field will be urged along the lines of force with a force of one dyne.*

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* *See* note § 44.

It is easy to map the field of force round any magnet since every magnet obviously tends to set itself parallel to the lines of force at the point where it is. If then the magnet whose field is to be mapped be laid down on a sheet of white paper and a small compass needle be moved about in its vicinity the direction of the needle at any point will give the direction of the lines of force at that point and these can be plotted on the paper. Again soft iron filings in a magnetic field become magnets themselves by induction and so set themselves along the lines of force mapping them out to the eye in a very beautiful manner.

This is an experiment which ought to be tried by every student and it will give a clearer idea of the lines of magnetic induction than any figure. The explanation of the fact that iron becomes strongly magnetic when placed in a magnetic field is due to the fact that the permeability of iron is very great, hence the same induction is able to produce a larger number of lines of force in iron than in air.

47. **Field of force about a wire carrying a current.**—To return to the electric current. We can now draw a deduction from Oersted's experiment, viz., that there must be a magnetic field of force about every wire that is carrying a current, and since, when we are facing the magnet and swimming with the current, the N pole is always deflected to the left whatever the position of the magnet with regard to the wire, it follows that the lines of force must pass round the wire in circles, and it is easily shown that they do so by scattering iron filings on a card, through a hole in which a vertical wire carrying a current is passed; when the card is tapped the filings instantly arrange themselves so as to map out the lines of force as circles

round the wire; also if we look along the wire from copper to zinc, *i.e.*, with the current, the direction of the lines, the direction in which a N pole will move, is that of the hands of a clock. If a wire be bent into the arc of a circle, when a current passes through this arc there will be a field of force at the centre of the circle due to the current at all points of the arc. If the arc were in the plane of the paper and the current ran counter clockwise* in it the direction of the lines of force would be vertically up from the paper.

The strength of the field of force at the centre will depend on the strength of current, the length of the arc and the length of the radius of the circle and on these alone. The intensity or strength of the magnetic field at the centre may be expressed as follows:—

$$I = \frac{l\,i}{r^2}\mu.$$

Where I stands for the intensity of magnetic field, i for the magnitude of current, l for the length of the arc, and r for the radius, while μ is the magnetic permeability and is therefore unity (see § 44), or this may be expressed thus:—

$$F = \frac{l\,i\,s}{r^2}$$

omitting μ since $\mu = 1$. Where F is the force exerted on a magnetic pole (North seeking) of strength s placed at the centre.

48. **Definition of unit current.**—Consequently if we make the arc of the circle to have a radius of one unit (one centimetre) and a length of one unit, we may define our unit current as that current which makes a field of unit strength at the centre, or, what amounts to the same thing, as that current which acting on a magnetic pole of unit strength at the centre urges it with unit force (one dyne). By this means the unit of current is defined in terms of the unit magnetic pole. And unit quantity of electricity may be defined as the quantity which passes any given point in a circuit in which unit current is flowing in unit time.

49. **Galvanometers.**—This definition of unit current

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* That is, in a direction opposite to that of the hands of a clock.

enables us to make an instrument for measuring the current in any circuit. Such an instrument is called a *galvanometer;* or when, as is frequently the case, it is used merely to indicate the presence of a current it may be called a *galvanoscope.*

In its simplest form, stripped of all non-essentials, the galvanometer consists of a coil of one or more turns of wire with a small magnet suspended freely at the centre. The coils may be, and generally are, circular but frequently for convenience of construction or other reasons they are wound in other shapes. The needle being suspended freely sets itself parallel to the magnetic field that happens to exist at the place where the galvanometer is to be used, and the coils of the instrument are then set parallel to the needle and therefore to the magnetic field at the place. Hence the field due to a current circulating in the coils will be at right angles to the permanent field with which it is to be compared (§ 50).

In order to read the deflections of the magnet when the galvanometer is in use, one of several devices may be applied. The simplest, where very accurate reading is not essential, is to attach to the magnet a very light long pointer which passes over a scale. Sometimes the scale is engraved on a piece of mirror and the position of the pointer on the scale can be determined with great accuracy when the eye is so placed that the pointer hides its own image in the mirror. The pointer is generally attached at right angles to the magnet so that its movements can be observed without hindrance from the coils. The pointer is often made of straw or aluminium or paper.

The sensitiveness of a galvanometer may be decreased by using a shunt to carry off part of the current, or by so placing permanent magnets as to make a strong field of force at the place where the needle is suspended

(§ 131). It may be increased by arranging permanent magnets in the neighbourhood so as to partly balance the earth's magnetic force at the place where the galvanometer is, or by using the so-called *astatic* combination of magnets. This consists of two needles rigidly connected and so magnetised that their poles are turned in opposite directions. This combination is hung with one needle inside the coils and the other outside. The earth's field fails to exert any directive action on the combination, as its action on one is counter-balanced by its action on the other; but the effect of the field of force of the coils acts in one direction on the poles of the needle within them, and, being itself reversed outside the coils, has an influence in the same direction on the reversed magnet there, and thus tends to turn the whole combination in one direction.

For the types of galvanometer used in medicine *see* § 131.

50. **Tangent and sine galvanometers.**—It is evident from what was said in § 47 that since the action of a current in a circular arc on a magnetic pole placed at the centre of the circle is proportional to the length of arc, the inverse square of the radius, the strength of the current, and the strength of the magnetic pole, *i.e.*,

$$F = \frac{l\ i\ s}{r^2}. \qquad \text{I.)}$$

Where F stands for the force, l for the length of arc, i for the current, s for the strength of pole and r for the radius of the circle, if we complete the circle l becomes $2\pi r$ (where π stands for the ratio of the circumference to the diameter of a circle $= 3{\cdot}14159$ or roughly $3\frac{1}{7}$) and the expression for a single circle of wire becomes

$$F = \frac{2\ \pi\ i\ s}{r}. \qquad \text{(II.)}$$

If we use a number of such circles (n) and r stands for the mean radius we get

$$F = 2\ n\ \pi\ i\ \frac{s}{r}. \qquad \text{(III.)}$$

Now we cannot obtain a single magnetic pole, and if we could the measurement of a force is a very difficult matter to carry out with accuracy, so that the practical method of using these principles is to balance the field of force due to the current at the centre of a galvanometer coil against a field of force obtained in some other way. Frequently the earth's field of force is the one chosen, but sometimes a stronger field is made by the use of a permanent magnet attached to or placed near the apparatus. Let us consider the action of a field of force on a magnet suspended at its centre O (fig. 8). Let the two fields of force be represented in magnitude and direction by lin O E, O C. Let m be the magnetic moment of the magnet, *i.e.*, the product of the strength of poles into l the length of the magnet. Then taking moments about the centre of the magnet, if θ be the angle of deflection produced by the superimposed field due to the current of magnitude O C (= say K)

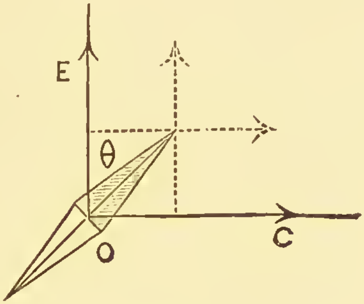

FIG. 8.—Diagram of fields of force and magnet in tangent galvanometer.

$$K\, l \cos\theta\, s = H\, l \sin\theta\, s \qquad \text{(IV.)}$$

where H represents the magnitude of the field O E, but $ls = m$ and disappears from the equations, therefore

$$K = H \tan\theta. \qquad \text{V.}$$

Now from our definition of strength of field $K = \dfrac{2\,n\,\pi\,i}{r}$ from equation III. (Since $K_s = F$).

Hence finally

$$i = \frac{H\,r}{2\,n\,\pi} \tan\theta. \qquad \text{(VI.)}$$

So that if we know the strength of the field of force when there is no current, the number of turns and the mean radius of the galvanometer coils we can by equation VI convert readings of the angular deflection of the galvanometer needle into current.

For instance suppose we have a current i circulating in a galvanometer of one turn of wire of 10 centimetres radius placed in the earth's magnetic field in England and the deflection of the needle is 45° then

$$i = \frac{H}{2\pi} \times 10 \times \tan 45^\circ.$$

Now tan 45° = 1 and in England H is about ·18 units.

$$\text{Hence } i = \frac{1\cdot 8}{6\frac{2}{7}}$$

nearly = ·287 absolute C.G.S. units of current = 2·87 ampères (*see* § 57).

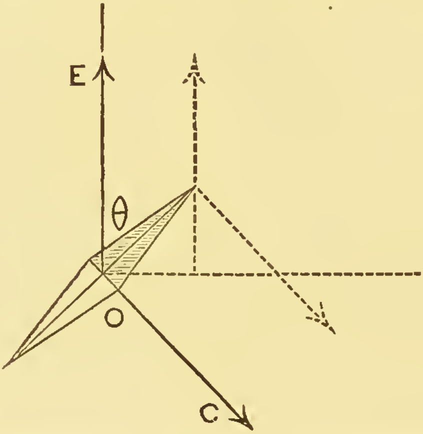

FIG. 9.—Diagram of fields of force and magnet in sine galvanometer.

There is another arrangement of galvanometer in which the coils themselves turn about a vertical axis (fig. 9). In this kind of galvanometer the coils and scale are turned until the needle again points to zero when the current is running, and the angle read is that through which the coils have been turned. Equation V then becomes

$$K = H \sin \theta \qquad \text{(VII.)}$$

as is easily seen, and VI reads

$$i = \frac{H\,r}{2\,n\,\pi} \sin \theta \qquad \text{(VIII.)}$$

The former kind of galvanometer is called a *tangent* galvanometer, and is the least trouble to use, but in the latter or *sine* galvanometer the angular readings are rather greater and in some cases this compensates for the greater trouble in use.

51. **Galvanometer constant.**—The factor

$$\frac{H r}{2 n \pi}$$

which converts the galvanometer readings into current is called the galvanometer constant, and is usually written as one symbol, G. It is generally determined for any given galvanometer once for all by driving a current through the galvanometer and a voltameter (§ 133). From the quantity of decomposition in the voltameter the average current can be arrived at with great accuracy, and the galvanometer constant can be determined by a comparison of this with the galvanometer reading. It is not usual to calculate the galvanometer constant from the coil itself as the mean radius is not easily arrived at.

52. **Ammeters and volt meters.**—It is possible to attach a specially calibrated scale to a galvanometer so that the readings shall be directly into current. A galvanometer that has been calibrated in this way is called an Ammeter (ampère meter). Such galvanometers are made for medical men to read milliampères or thousandths of an ampère (§ 131), and often give fairly accurate results, especially as it will be seen from equations VI. and VIII., that the readings do not depend on the magnetic moment of the magnet of the galvanometer; the calibration, however, should always be checked from time to time by the user. A galvanometer of high resistance, that is to say one of such resistance that the resistance of a battery is negligeable by comparison with it, may be used to compare the

electromotive forces of batteries, it is then called a Volt meter.

53. **Reflecting galvanometer.**—Some special forms of ammeters and volt meters will be described in a future chapter, we may, however, here just mention the *reflecting galvanometer*. This is more generally used as a galvanoscope, and is very sensitive. It is so called because the motions of the magnet are made visible by a beam of light which is reflected on to a scale from a small mirror attached to the magnet. By the laws of reflection of light, the angular deflection of the reflected beam of light is twice that of the mirror. The apparent angular motion of the magnet is therefore doubled, and the motion of the spot of light on the scale can be increased by removing the scale to a great distance from the mirror.

54. **Unit of electromotive force.**—Now a current is set up in a circuit by electromotive force (*see* def. § 22); that is to say the current in any part of a circuit is due to the difference of potential between the ends of that portion of the circuit. This can be measured by means of an electrometer. But from the definition of potential in § 25 we see that the difference of potential between any two points A and B is measured by the work done in bringing up unit quantity of electricity from B to A against the electrical forces of the system under consideration, hence the work given out when unit quantity of electricity runs down from A to B under the electrical forces of the system is equal to the difference of potential between A and B. Hence, if we write E for this difference of potential between A and B, *i.e.*, the electromotive force from A to B, we get an expression

$$Eq = W.$$

Where q stands for the number of units of electricity run down under electromotive force, E and W for the work done. But $q = Ct$ where C is the current and t the time during which we consider it as running. Hence, we may write $ECt = W$. So that we may define our unit of electromotive force thus:—In any part of a circuit carrying unit current, unit work is done in unit time when the electromotive force between the ends of that part of the circuit is unit electromotive force.

55. **Resistance.**—It is soon found in working with currents that with different amounts of wire in the circuit, different currents are produced by the same electromotive force. There is another factor that determines the strength of current besides the electromotive force, and this factor is called the *resistance* of the circuit. (*N.B.* Simple circuits and steady currents only are here considered, with variable currents it will be found that there are yet other factors that affect the matter).

56. **Ohm's law.**—The law showing the relation between electromotive force, resistance and current was enunciated by Dr. G. S. Ohm and is known as Ohm's law. It is as follows:—*The strength of the current in any circuit or part of a circuit varies directly as the electromotive force in that circuit and inversely as the resistance of the circuit.* This may be expressed in symbols thus:—

$$C = \frac{E}{R}.$$

Where C stands for the current, E for the electromotive force, and R for the resistance. As before, in the case of other units, the unit of resistance is taken as the resistance which with an electromotive force of unit value allows unit current to pass.*

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* The unit of capacity is defined in the same manner as it was in electrostatics, though it is of course a different magnitude. This is scarcely required in medical work.

We have now defined the most important of the electro-magnetic units. As in the case of the electrostatic units, these are all ultimately defined in terms of the units of mass, length and time, and as in all electrical and other scientific calculations these are taken to be one gramme, one centimetre and one second respectively, the system of units here defined is known as the absolute or centimetre-gramme-second (C.G.S.) system. It is found, however, that for practical calculation and use these units are not of a convenient size, *e.g.*, the units of electromotive force and of resistance are inconveniently small, and that of current is inconveniently large. A system of units has therefore been derived from these as follows :—

57. **Practical units.**—*Electromotive force.*—The practical unit consists of one hundred million absolute units (10^8)*, and is called the *Volt.* It is a little less than the electromotive force of one Daniell's cell.

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* "Seeing that electricians have to deal with quantities requiring in some cases very large numbers, and in other cases very small numbers to express them, a system of index notation is adopted in order to obviate the use of long rows of cyphers. In this system the significant figures only of a quantity are put down, the cyphers at the end, or (in the case of a long decimal) at the beginning, being indicated by an index written above. Accordingly we may write a thousand ($10 \times 10 \times 10$) as 10^3, and the quantity 42,000 may be written 42×10^3. The British National Debt of £770,000,000 may be written £77×10^7. Fractional quantities will have negative indices when written as exponents. Thus $\frac{1}{100}$ (0·01, $= 1 \div 10 \div 10 = 10^{-2}$ and so the decimal ·00028 will be written 28×10^{-5}, being $28 \times$ ·00001. The convenience of this method will be seen by an example or two on electricity. The electrostatic capacity of the earth is 630,000,000 times that of a sphere of one centimetre radius $= 63 \times 10^7$ (electrostatic) units. The magnetic moment of the earth is, according to Gauss, no less than 85,000,000,000,000,000,000,000,000 times that of a magnet of unit

Resistance.—One thousand million (10^9) absolute units is called the *Ohm.* The Paris Congress of Electricians in 1884 defined an unit of resistance to be called a "*legal Ohm.*" It is represented by the resistance of a column of pure mercury at 0° C., one square millimetre in section, and 106 centimetres long, it is less than the true ohm by about ·3 per cent. (§ 62).

Current.—The current which is given by an electromotive force of one volt acting through a resistance of one ohm (*i.e.*, one-tenth (10^{-1}) of an absolute unit) is called one *Ampère* (this was formerly known as one Weber).

Quantity.—One ampère for one second carries one *Coulomb* of electricity, *i.e.*, 10^{-1} absolute units, past any point in the circuit. Another unit of quantity much used by engineers is the quantity of electricity which would be carried by one ampère in an hour. This is called an *ampère-hour.* It is equal to 3600 coulombs.

Capacity (see § 30).—That capacity which would require one coulomb to charge it to one volt, *i.e.*, one one-thousand-millionth (10^{-9}) of the absolute unit of capacity, is called one *Farad.*

Even these units are inconveniently great or small at times, so certain prefixes are used to the names to denote multiples or sub-multiples of these quantities. Thus, a *megohm* is one million (10^6) ohms, a *micro-volt* is

strength and one centimetre in length, *i.e.*, its magnetic moment is 85×10^{24} units. The resistance of selenium is about 40,000,000,000 or 4×10^{10} times as great as that of copper: that of air is about 10^{26} or 100,000,000,000,000,000,000,000,000 times as great. The velocity of light is about 30,000,000,000 centimetres per second, or 3×10^{10}; as a final example we may state that the number of atoms in the universe, as far as the nearest fixed star, can be shown to be certainly fewer than 7×10^{91}." (*S. P. Thompson's* "Lessons in Electricity and Magnetism.").

one-millionth (10^{-6}) of a volt, a *microfarad* one-millionth (10^{-6}) of a farad, a *milliampère* is one-thousandth of an ampère; this last is the unit of current used in medicine.

58. **Electrolysis.**—In § 40 it was pointed out that during the passage of an electric current through a battery the liquid, or as we then called it the electrolyte, was decomposed, and this decomposition is essential to the passage of the current. Examining into the decomposition more closely, it may be looked on as if it took place as follows :—Owing to the difference of potential set up between the plates, say of zinc and copper, the zinc plate being positive attracts to itself the electronegative portion or *ion* of the electrolyte. In the case of sulphuric acid (H_2SO_4) this is the group of atoms SO_4. At the same time the copper plate being at the lower potential, and therefore negatively charged with regard to the zinc, attracts the electropositive *ion*, *i.e.*, the hydrogen, and the state of affairs may be thus represented,

$$\begin{array}{cccccccccc} Zn & SO_4 & H_2 & SO_4 & H_2 & SO_4 & H_2 & SO_4 & H_2 & Cu \\ + & - & + & - & + & - & + & - & + & - \end{array}$$

i.e., a chain of molecules polarized under the influence of the contact difference of potential between copper and zinc. But the *ion* SO_4 is capable of combining with the zinc and so neutralising its positive charge, and the *ion* H_2 is set free on the copper, thus neutralising the corresponding negative charge there. Immediately of course the same action recurs owing to the continuously acting contact electromotive force between copper and zinc.* In this way a continuous current is kept up, and a continual double procession of the molecules of the electrolyte or ions occurs in the liquid part of the circuit, the electropositive ion passing always towards the copper or positive pole of the battery and the electronegative ion towards the zinc, so that we may regard the copper plate as receiving positive electricity continually from the electrolyte, and passing it on to the circuit. The hydrogen given off at the copper plate does not escape instantaneously, and unless means are taken for removing it, it will set up a back or reverse electromotive force which will greatly reduce the efficient electromotive force of the battery. The battery is then said to be *polarized.* Many methods, chemical and mechanical, have been suggested for overcoming this difficulty, some of which will be described in Chapter V.

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* It is fair here to call attention to the fact that this explanation has been, and is strongly disputed, especially by Dr. Lodge, who gives an alternative one in the place referred to above. Some lately published researches by Dr. Weeren, on the action of acids on zinc, seem to strengthen the position taken up by the objectors. (See note in "Nature" for July 16th, 1891, p. 259).

If the wires leading from the terminals of a battery are not joined but are led into another electrolyte, an action corresponding to that which takes place in the battery will occur. There will be a tendency to decompose the electrolyte, and if there is sufficient electromotive force in the circuit to overcome the reverse electromotive force of the electrolyte, electro-decomposition or *electrolysis* will take place. Taking the case of water (in practice the water is slightly acidified with sulphuric acid to increase its conductivity) the changes are as follows:—

59. **Anode and kathode.**—Suppose that the poles of the battery are connected to two platinum plates in the water. These plates are called the electrodes. That connected with the copper pole is the one by which the current (considered as a flow of positive electricity) enters the electrolyte and is called the *Anode*, that connected with the zinc is called the *Kathode*, *i.e.*, the pole by which the current leaves the solution. In

the beginning the anode is positive, the kathode negative. The ions in the case of water are hydrogen and oxygen and the former is electropositive and therefore appears at the kathode or negative pole and is called the *kation*, while the oxygen appears at the anode and is called the *anion*. The arrangement of the molecules may be represented thus :—

To zinc pole, Kathode H_2 O H_2 O H_2 O Anode, to copper pole.
— + — + — + — +

If the electromotive force of the battery is not sufficient to overcome the back electromotive force due to the chemical affinity of the oxygen and hydrogen for each other, matters will rest like this, the electrolytic cell is *polarized*,* the current is stopped, and no appreciable decomposition or electrolysis will take place, but if the electromotive force is sufficient, *i.e.*, about 2 volts or more, decomposition will proceed, hydrogen being given off at the kathode, and oxygen at the anode.

60. **Laws of electrolysis.**—The laws of electrolysis were discovered by Faraday ; † they are as follows :—

a. The amount of chemical action is equal at all parts of a circuit. E.g. If a circuit is made containing several electrolytic cells, or *voltameters*‡ as they are often called, the amount of decomposition will be the same in each. If they are water voltameters the same amount of hydrogen will be given off in each, if the electrolyte is copper sulphate solution the same amount of copper will be deposited in each. The same applies in the case of the kations. If some of the voltameters contain water and others contain sulphate of copper solution, the quantities of hydrogen and copper respectively will be proportional to their chemical equivalents.

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* It is easy to show that there is an actual reverse electromotive force in the electrolytic cell, by suddenly cutting out the battery and completing the circuit in which the electrolytic cell is included through a galvanometer, which will then indicate a small current in the opposite direction.

† "Experimental Researches," Series V. and VII.

‡ For an account of Voltameters, see § 133 to 135.

b. The amount of any ion liberated in any given time is proportional to the strength of the current, and to the chemical equivalent of the ion.—This may be expressed thus :—

$$W = C \alpha w t.$$

Where W stands for the weight of the ion liberated, C for the current, w the chemical equivalent of the ion, t the time for which the current runs and α is a constant.

61. **Electro-chemical equivalents.**—Since the equivalent w for hydrogen is unity we see that α is the weight of hydrogen liberated by one ampère running for one second, *i.e.*, by one coulomb of electricity, and this is called the electro-chemical equivalent of hydrogen. For any other ion the product αw, *i.e.*, the constant multiplied by the chemical equivalent of the ion is called the electro-chemical equivalent of that ion. The electro-chemical equivalent of silver was determined with the most elaborate care by Lord Rayleigh and Mrs. Sidgwick[*] in the Cavendish Laboratory at Cambridge and was found to be ·00111794[†] grammes per coulomb, *i.e.*, the quantity of silver which one ampère would deposit in an hour is 4·0246 grammes. Now the chemical equivalent of silver is the same as its atomic weight and was determined by Stas to be 107·938.

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[*] Roy. Soc. "Phil. Trans," 1884, vol. ii., p. 411.

[†] The number ·001118 is that recommended to be adopted in the report of the committee on electrical standards to the Board of Trade, dated July 23rd, 1891.

Hence the electro-chemical equivalent of hydrogen will be per coulomb

$$\frac{\cdot 00111794}{107\cdot 938} = 1\cdot 0357 \times 10^{5}.$$

62. **The legal ohm.**—Since in modern times the electric current has become an article of commerce it has become important to define standards of electric quantities accurately by law, and the legal unit of resistance, or *legal ohm*, was defined at the Paris Congress as the resistance of a column of mercury of a certain length and thickness, viz., 1060 millimetres in length and one square millimetre in section. This differs probably by less than one-third per cent. from the true value of the ohm, viz., 10^9 absolute units, and all resistances are expressed in terms of it. Standard resistance coils are made with which to compare unknown resistances just as there are weights and yard measures with which to compare unknown weights and lengths.

63. **Specific resistance.**—The electrical resistance of any material is a property peculiar to that material just as its hardness or colour or density is. Most metals are good conductors but they vary greatly among themselves in their electrical conductivity. Silver is the best conductor of electricity and copper comes near to it. Platinum has about 6 times, and German silver about 14 times the resistance of silver. Tables showing the relative conductivity of metals and other bodies are given in text-books such as *S. P. Thompson's* "Lessons."

Tables of resistance are also made with the *specific resistances* of the materials tabulated. Such tables will be found in *Everett's* "Units and Physical Constants" or in *S. Lupton's* "Numerical Tables."

In all these the specific resistances are given in terms of the B. A. unit of resistance, which is ·9893 of the legal ohm and ·98655 of the true ohm, or 10^9 C.G.S. units. The specific resistance of mercury is $9{\cdot}4073 \times 10^5$ true ohms.

The specific resistance of a material is defined as the resistance of one cubic centimetre of the substance considered.

If the specific resistance of a substance is known, the resistance of any wire or rod of that substance can be calculated.

For example, the specific resistance of a certain sample of copper is 1642 absolute units ($= 1642 \times 10^{-9}$ ohms); it is required to calculate the resistance of one mile of wire of No. 18 S.W.G.* made of this copper. One mile may be taken as $1{\cdot}609315 \times 10^5$ cm. The diameter of a wire of No. 18 S.W.G. is ·048 inch = ·1219 cm., and the sectional area is ·0117 sq. cm. Hence the resistance in ohms will be

$$1{\cdot}642 \times \frac{1{\cdot}609}{1{\cdot}17} \times 10 = 22{\cdot}5 \text{ ohms about.}$$

In general the resistance of metals increases with temperature. That of carbon, however, decreases considerably. An incandescent lamp has, according to Mr. J. E. H. Gordon, nearly twice the resistance cold that it possesses when hot.

64. **Resistance of an electrolyte.**—Just in the same way as the resistance of a metal or other solid conductor is considered, we may speak of the resistance of a liquid or electrolyte. There is more difficulty in measuring this in practice in consequence of the reverse electromotive force of polarisation, but if alternate currents be used the specific resistance of an electrolyte may be found, uncomplicated by polarisation effects. The fact that electrolysis is taking place in an electrolyte does not prevent the consideration of its resistance in the same way as that of a non-electrolyte. The

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* S.W.G.—Standard Wire Gauge.

specific resistance of water is high, and the purer the water the higher it becomes; it would appear, according to the latest experiments that absolutely pure water if it could be obtained would be a perfect non-conductor.

65. **Measurement of resistance.**– Ohm's law may be applied to measure the resistance of any given conductor, or rather to compare the resistances of two conductors.

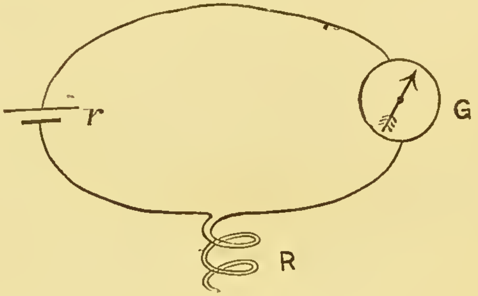

FIG. 10—Typical circuit.

Suppose that the constant of the galvanometer (§ 51) is known, *i.e.*, that the current, passing through a galvanometer can be read off from the deflection of the needle, and it is required to find the value of the resistance R. Join up the resistance R with the galvanometer and battery as in the figure, then since by Ohm's law

$$C = \frac{E}{R_0} \text{ and } E = R_0\, C.$$

if C, the value of the current is known and also E the electromotive force of the battery, R_0, the resistance of the whole circuit, is known from the equation. But this is made up of R the resistance to be measured, and r the resistance of the battery, and g that of the galvanometer. Subtracting, $R_0 = R - r - g$. *E.g.* Suppose a

Daniell's battery of electromotive force 1·08 volts and resistance ·58 ohms, and a galvanometer whose resistance is 66·3 ohms are used, and the reading of the galvanometer is ·006 ampère (six milliampères) we get

$$1{\cdot}08 = (R + {\cdot}58 + 66{\cdot}3)\ {\cdot}006$$
$$R = 180 - 66{\cdot}88 = 113{\cdot}12 \text{ ohms.}$$

In practice, however, we can never rely on knowing the electromotive force or resistance of the battery with sufficient accuracy for this, so the method must be so modified as to eliminate these.* Methods of doing this are described in "Practical Physics" by *Glazebrook* and *Shaw*, in the "Textbooks of Science" series, or in "Practical Physics" Vol. II., by *Balfour Stewart* and *Gee.*

By obvious modifications this method may be used for the determination and comparison of the resistances of batteries or galvanometers, or for the determination of the electromotive force of a battery.

66. **Network of conductors.**—Ohm's law may be applied to any portion of a circuit, and hence by its help it is possible to determine how a current splits itself up in a network of conductors.

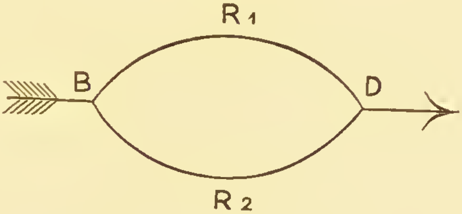

FIG. 11.—Divided circuit.

Consider such a circuit as in the figure. Let C be the current in the part of the circuit outside B D, it is required to find what portion is carried by each wire from B to D. Let the resistances of the wires be R_1 R_2, and let E be the electromotive force between B and D, and $x\ y$, the currents in the branches R_1 R_2, then applying Ohm's law to each :—

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* The method is often useful for finding roughly the resistance of a battery.

$$x = \frac{E}{R_1},\ y = \frac{E}{R_2},\ \text{but } x + y = C, \text{ the whole current,}$$

$$\text{hence } \frac{E}{R_1} + \frac{E}{R_2} = C \text{ and } E = C\,\frac{R_1\ R_2}{R_1 + R_2},$$

$$\therefore x = C\,\frac{R_2}{R^1 + R_2}, \text{ and } y = C\,\frac{R_1}{R_1 + R_2}.$$

E.g., let $R_1 = 9$ ohms, $R_2 = 1$ ohm, then the effective resistance between B and D is $\frac{9}{10} = {\cdot}9$ ohms. $\frac{1}{10}$ of the current passes the resistance R_1, and $\frac{9}{10}$ through the resistance R_2. This is the method used to shunt a galvanometer so that a certain fraction only of the current shall pass through it. For instance, a galvanometer whose resistance is 66 ohms, will have a shunt whose resistance is 7·33 ohms if it is required to be $\frac{1}{10}$ as sensitive.

The laws which regulate the division of a current in branched circuits were formulated by Kirchoff. They can be deduced mathematically from Ohm's law and are as follows :—

a. In any branching network of wires the algebraic sum of the currents in all the wires that meet in a point is zero.

b. When there are several electromotive forces acting at different points of a circuit, the total electromotive force round the circuit is equal to the sum of the resistances of its separate parts multiplied each into the strength of the current that flows through it.

67. **Wheatstone's bridge.**—Second method of comparing resistances (fig. 12). There is a continuous fall or slope of potential along both paths from B to D, *e.g.*, if we examine the electromotive force between C and D, we

shall find that it bears the same proportion to the electromotive force from B to D that the resistance *c* does to the whole resistance from B to D *via* C, viz., $a + c$. If now we choose a point A in BAD, so that the resistance x from A to D is to the whole resistance from B

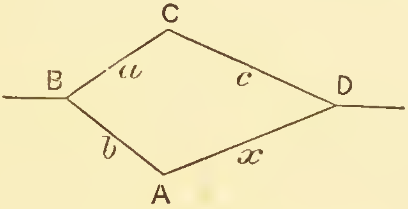

FIG. 12.—Divided circuit.

to D *via* A in the same proportion as *c* is to $a + c$, the potential at C and A will be the same; and if we join C A by a wire through a galvanometer, there will

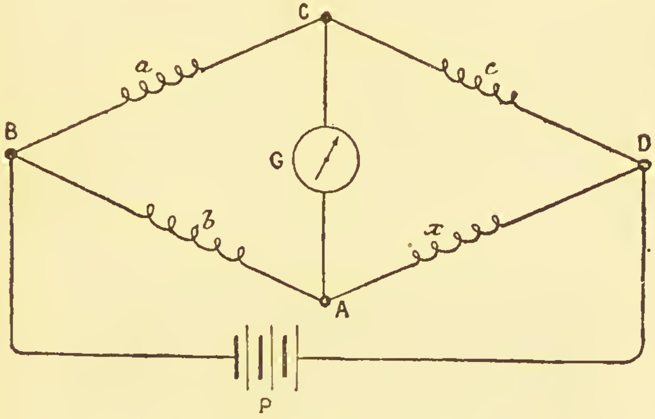

FIG. 13.—Wheatstone's Bridge.

be no current through the galvanometer. Such an arrangement is known as a Wheatstone's bridge or balance and is diagrammatically represented as in the figure (fig. 13). If a b c x are the resistances of the various branches as drawn, when there is no current in the galvanometer, we have the relation $a : b = c : x$, and if any three of the resistances are known, the fourth can be calculated from this proportion. This is the most generally useful and convenient method of determining a resistance, and a set of resistance coils is sold by instrument makers in the most convenient form for this purpose. This is known as a post-office box. A diagram of it is shewn in fig. 14, and a drawing of it in fig. 15. The resistance to be tested is joined to the binding screws at C and D, the battery is joined to

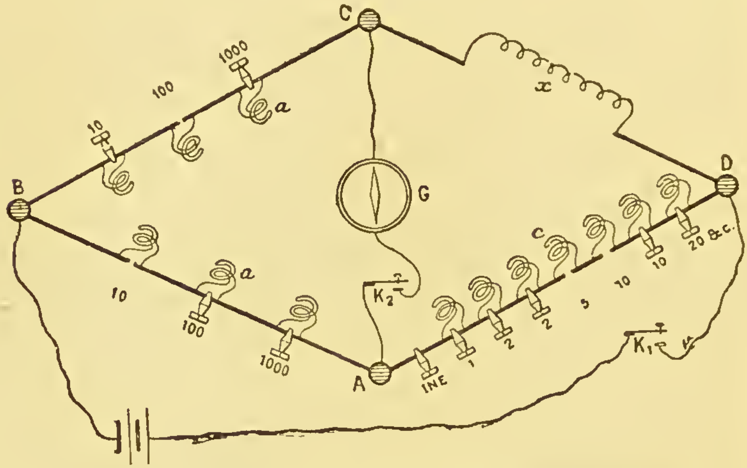

Fig. 14.—Wheatstone's Bridge. Measurement of resistance.

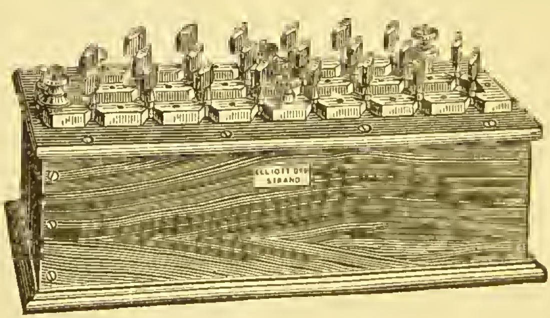

Fig 15.—Resistance box.

the screws at B and D, and the galvanometer to those at A and C. By taking out the proper plugs in the arms, BA, BC, these may be made equal in resistance, in which case, to get a balance, the resistance plugs that are taken out in the arm AD, will give the resistance of the coil to be tested. Or BA may be made 10 or 100 times BC, in which case the readings on AD divided by 10 or 100 as the case may be, will be equal to that in the coil to be tested, so that by this artifice it is possible, though not using any resistance coil of less than one ohm, to find the resistance of the wire to be tested correct to $\frac{1}{100}$ of an ohm. For further details as to the use of this instrument, the various forms it takes, the precautions in working with it, and for a description of the coils and the way they are wound and adjusted, reference must be made to the above mentioned books, or to *Kempe's* "Handbook of Electrical Testing," or any modern text-book of electricity. Methods also will be found described of adjusting the Wheatstone's bridge arrangement to find the internal resistance of the battery, or the resistance of the galvanometer.

68. **Current sheets. Current density.**—When a current is led into a large conductor the lines of flow spread out through the conductor in a manner somewhat similar to the spreading of the magnetic lines of force. They all of course pass from the anode to the kathode, but they spread out into sheets in doing so. The current which passes across unit of sectional area, taken at right angles to the lines of flow at any point, may be called the *density* of the current at that point. In the case of a current in a wire conductor we consider the whole current since the whole sectional area of the wire is taken into account, but with currents flowing in large

and heterogeneous conductors like the human body, or even in electrolytes where the density of the current may vary from point to point, it is necessary in order to estimate the effect at any point, to take into consideration the density at that point rather than the whole current. For the physiological effects are largely dependent on the density, that is the ratio of current to sectional area, just as in a wire, the heating effect is, other things being equal, proportional to the square of this ratio. For example, in a wire of variable diameter the heating effect will be far greater in the thinner parts of the wire, where the density of the current may be said to be greater, though the actual current in all parts is the same. In a conductor such as the human body, some of the lines of flow of the current will leave any muscle or nerve quite near the electrode by which they enter, and will pass to the other electrode through the other tissues. This gives rise at times to a series of virtual electrodes along the course of a nerve which may be of some importance. (See Chap. VII.).

69. **Internal resistance of batteries. Arrangement of batteries.**—In arranging a battery to give the best effect in any given case regard must be had to its internal resistance. It is impossible to give any exact figures as to the internal resistance of various batteries, but a rough indication will be found in Chap. V. That of a Daniell's cell should not much exceed one ohm, a "Sawdust" Daniell (*i.e.*, a Daniell's cell packed with sawdust to prevent spilling of the liquid, a very convenient form of battery for testing purposes) may have ten or more ohms, a Leclanché cell may have a resistance of from one to five ohms. Some idea of the resistance of any particular cell may be obtained by such a measurement as that in § 65. Anyhow it is

of the utmost importance to have some knowledge of the resistance of the battery in order to know whether for any purpose it is best to arrange the cells that are to hand in series (fig. 16) or in parallel (fig. 17).

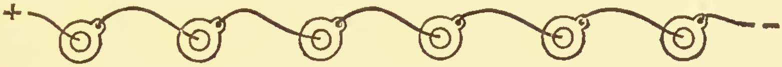

FIG. 16.—Six cells arranged in series.

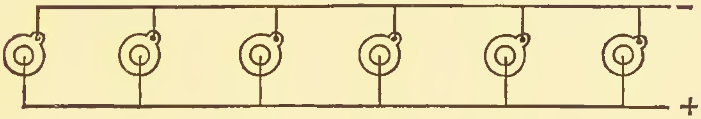

FIG. 17.—Six cells arranged in parallel.

The general guiding principle is as follows:—For any given number of cells the maximum current is obtained when the batteries are so arranged that the internal and external resistances are equal. Thus, if a cautery of low resistance is to be heated, it is useless to use a number of batteries of high internal resistance in series. Suppose the resistance of a cautery is ·1 ohm and the batteries to hand are ten bichromate cells of 1·6 volts each and one ohm internal resistance each, and suppose that the cautery requires five ampères to heat it. If the cells are coupled up in series the electromotive force will be sixteen volts, but the internal resistance of the ten cells is ten ohms and the total resistance is 10·1 ohms, and this will give a current of 1·58 ampères, but if they are coupled in parallel, the battery resistance will be reduced to ·1 ohm, and the total resistance will be but ·2 ohm in the whole circuit. True the electromotive force will be only 1·6 volts, but by Ohm's law (§ 56) the current in this case will be eight ampères. In the former case the cautery would not be heated, in the latter we should have enough current and to spare. *Vice versâ*, it is futile to arrange batteries in parallel when a current has to be passed through a high resistance, such as the human body, a resistance of at least 1000 ohms, compared with which the internal resistance of sixty Leclanché cells in series is small.

Taking the electromotive force and internal resistance of the cells as before, it will be useful to give illustrations of the results of coupling up six cells in different ways. If in series (fig. 16) the electromotive force is 9·6 volts, and the internal resistance is six ohms, hence the maximum current that could be obtained would not much exceed 1·5 ampères. In a series of three, each of two set in parallel (fig. 18), the total internal resistance will be 1·5 ohms, and the electromotive force 4·8 volts, and it would be possible to take a current of over three ampères from it. In a series of two sets of three each in parallel (fig. 19) we should get an internal resistance of ·66 ohms, and an electromotive force of 3·2 volts, which could give over 4·5 ampères. Finally, with all in parallel (fig. 17) there is an internal resistance of ·166 ohms and an electromotive force of 1·6 volts, so giving a maximum current of nearly ten ampères. The above calculations all suppose the battery to be short circuited, and therefore doing no external useful work ; they also

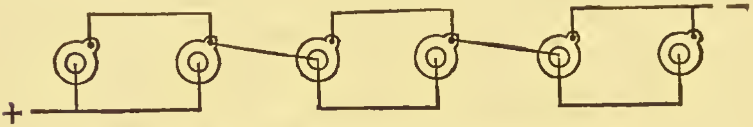

FIG. 18.—Six cells arranged in a series of three pairs.

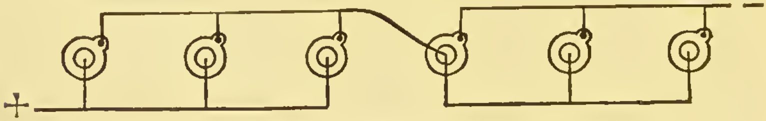

FIG. 19.—Six cells arranged in a series of two triples.

leave out all consideration of polarisation (§ 40). From the accompanying table in which the current obtained from each arrangement of the cells for an external resistance of ·2, 1, 2, 5, and 1000 ohms is tabulated, it will be seen that in each column the largest current is obtained when the external resistance is most nearly equal to the internal resistance of the battery; while in the case of the large resistance of 1000 ohms the internal resistance of each combination is negligeable, the current being almost exactly proportional to the electromotive force.

Case.	Internal resistance.	Electromotive force.	External resistance in ohms.					
			·2	1	2	5	1000.	
1	6 ohms.	9·6 volts.	1·5	1·4	1·2	·87	·0095	amp.
2	1·5 ,,	4·8 ,,	2·8	1·9	1·4	·74	·0048	,,
3	·666 ,,	3·2 ,,	3·7	2·0	1·2	·57	·0032	,,
4	·166 ,,	1·6 ,,	4·4	1·4	0·74	·31	·0016	,,

70. **Heating effects.**—It was pointed out in § 54 that there is a relation between the electromotive force in a circuit and the current and the work done in the circuit which was expressed by the following relation :—$E\,C\,t = W$. Where E stands for the electromotive force, C for the current, t for the time considered and W for the work done. Let us now write P for power or rate of doing work in this equation, then provided t is small enough $P\,t = W$ and the equation becomes $E\,C = P$. If E and C are measured in absolute electromagnetic units P will be measured in ergs per second.

The *Erg* is the absolute C.G.S. unit of work, the work done by one dyne acting through one centimetre. The attraction of gravity is about 981 dynes on every gramme, consequently, to raise one gramme one centimetre against gravity requires an expenditure of 981 ergs.

But if we measure E and C in volts and ampères, W will be given in a unit which is equal to 10^7 ergs per second and is called a *watt.*

One watt for one second will do 10^7 absolute units, ergs, of work and this amount is called one *joule*. A watt is not necessarily an electrical quantity, but is a rate of doing work like a "horse power." The rate of working, viz., the product of electromotive force into current, in an incandescent lamp is generally expressed in watts. A good lamp should require about four watts per candle power.

By Ohm's law the above equation may be expressed in several different ways. Thus substituting the value of C from the equation $C = \frac{E}{R}$ we get $\frac{E^2}{R} = P$ or again we may substitute the value of E from the same equation and so get $C^2 R = P$. We have therefore these three expressions for the rate of expenditure of energy by a current in a conductor. In any simple wire conductor this work appears as heat. We are consequently able to calculate the rate at which heat is generated in the conductor and if we know its specific heat and the rate at which it loses heat at its surface we can calculate the temperature after the current has passed for any given time.

Consider a conductor of resistance R, carrying a current C, we have $C^2 Rt = W$; where t is the time. But $W = J H$ where H stands for the heat developed, measured in calories, and J is the mechanical equivalent of heat which may be expressed in ergs if we are using absolute C.G.S. units, or in joules, if we are using practical units (volts and ampères, &c.).

Hence $C^2 R t = J H$. Now let m be the mass of the conductor and s its specific heat; then

$$H = s m \theta$$

where θ stands for the rise in temperature in degrees centigrade.

Substituting

$$C^2 R t = J s m \theta \text{ or } \theta = \frac{C^2 R t}{J s m}$$

To fix our ideas let us consider the example given in § 69. We had a platinum wire cautery of resistance ·1 ohm, let us suppose it to have a diameter of ·25 mm., and a length of 5·25 cm.; such a wire will have a resistance of about ·1 ohm and a mass of ·056 grammes. The specific heat of platinum is ·035. The mechanical equivalent of heat is $4{\cdot}2 \times 10^7$ ergs but one joule is 10^7 ergs. Hence J in joules is 4·2. If t is one second we get the following equation for the rise of temperature per second, omitting the loss from radiation.

$$C^2 \times \cdot 1 = 4\cdot 2 \times \cdot 035 \times \cdot 056 \times \theta.$$

If now C is 5 ampères

$$\theta = \frac{25 \times \cdot 1}{4\cdot 2 \times \cdot 035 \times \cdot 056} = \frac{2\cdot 5}{4\cdot 2 \times 3\cdot 5 \times 5\cdot 6} \times 10^4 = 303^\circ \text{ C per second.}$$

The wire then should begin to glow in about 2 or 3 seconds and if there were no loss by radiation it should melt in six or seven seconds. However, had we coupled the cells in series instead of in parallel the current would have been but 1·58 ampères and the rise in temperature per second, exclusive of loss would have been but 30° C.

Note on Joule's equivalent.—Probably one of the most remarkable advances that science has made in the nineteenth century is the proof that heat and energy are convertible. We owe this addition to our knowledge to the labours of many great scientific men from Benjamin Thomson, Count Rumford, down, but to James Prescott Joule belongs the credit of having determined by an exhaustive and beautiful series of experiments, carried out with the utmost care, the numerical relation that exists between heat and energy. He showed that if 775·47 foot pounds of work as done at Manchester were completely converted into heat, it would suffice to raise the temperature of one pound of water by one degree Fahrenheit. This number converted into C.G.S. units and degrees centigrade gives $4\cdot 175 \times 10^7$ ergs as the quantity of work that must be done to raise the temperature of one gramme of water by one degree centigrade. The quantity of heat required to do this is defined as the unit of heat and is called one *gramme degree* or one *calorie* or one *therm*. Hence 41·75 million units of work are equivalent to one calorie.

71. **Electro-magnetic induction.**—Let us consider a coil of wire the ends of which are connected through a galvanometer. If a magnet be made to approach such a coil the galvanometer will indicate a current so long as the magnet is approaching. As soon as the magnet stops approaching, the current also ceases. If now the magnet be removed the galvanometer will indicate a current in the opposite direction. If the coil is made to approach and recede from a magnetic pole the same

effects will be produced. In § 46 it was shown how a magnetic field might be mapped similarly to the electric field described in § 36. A little consideration of the last experiment will show that the approach of the magnet to a coil means the increase of the number of magnetic lines of force which pass through the coil, and that when the magnet is moved away the number of lines of force through the coil, or in other words the strength of field in the interior of the coil diminishes. This effect of a varying magnetic field on a coil of wire placed in it is known as *electro-magnetic induction*. It was discovered and investigated by Faraday and the account of his experiments is contained in his "Experimental Researches."

72. **Laws of electro-magnetic induction. Lenz's law.**—Before proceeding to discuss these effects further it may be well to specify and clear up our ideas as to direction of currents and fields of force. Let us consider a coil of wire in the plane of the paper with a current circulating in it counter-clockwise in the direction of the arrow (Fig. 20). The magnetic field of force at the centre of the circle due to this current will be at right angles to the paper and by our convention as to signs, since according to Oersted's law (§ 41) a north-seeking pole will be pushed upwards from the paper, the magnetic lines of force are directed upwards from the paper. The circle of wire acts like a magnetic disc, the upper side of which is N and the lower S. Indeed

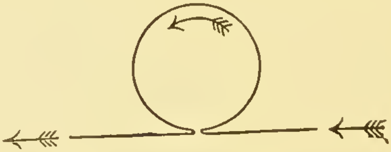

FIG. 20.—Electromagnetic induction.

if such a circuit be suspended freely it will set itself in the earth's magnetic field so that the upper side faces towards the North. Now suppose there is no current in the wire and it is placed in a magnetic field similar to that created by the current that we have described, then as the field *increases* the current induced in the wire would be in the opposite sense to the current that creates such a field, viz., in the present case it would be clockwise, and as the field *decreases* it would be in the same sense, viz., counter-clockwise. This may be formulated once for all by saying that the induced current is such that the field it would set up tends to neutralize the change in field that is causing it. (Lenz's law).*

Obviously more coils than one may be arranged to be acted on together and the same rule holds good, so that if we increase a magnetic field which is such that it is positive from below upwards, the induced current will flow clockwise and therefore downwards through a right handed helix and *vice versâ*. It is clear that since the induced current depends on the variation of the magnetic field in which the coil is placed, and on this alone, it matters nothing whether the field is caused to vary by moving a magnet or by making and unmaking a magnet by any means or by varying a current in another neighbouring circuit. It will be easily seen that when a clock-wise current is made in an inducing circuit (called a *primary circuit*), the current in the circuit that is being acted on (called the *secondary circuit*) is counter clock-wise, but that when the current in the primary is broken, that in the secondary is clock-wise, *i.e.*, when the current in the primary is made the induced current in the secondary is in the opposite direction, but when it is broken the induced current is in the same direction.

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* These facts enable us to understand the rapid damping of the oscillations of a magnet or a galvanometer needle enclosed in a mass of conducting metal, for as the N pole of the magnet approaches each fresh part of the metal eddy currents are induced in it of such a nature that the field they set up tends to repel the magnet and as it recedes the reverse occurs. Hence the swing of the magnet is checked at both times and it is rapidly brought to rest.

73. **Induced electromotive force.**—In order to arrive at the magnitude of the induced current we must consider that by Ohm's law this depends on two quantities, the electromotive force in the circuit and the resistance of the wire. This latter is constant since it depends only on the wire. The electromotive force alone varies. Its direction we have sufficiently considered, its magnitude is determined by the following law :—The total induced electromotive force in any closed circuit is proportional to the *rate of change* of the number of lines of force through the space enclosed by the circuit ; the " lines of force " being measured according to the convention made in discussing electrostatic lines of induction (§ 36).*

If we are concerned with the induction between two circuits, the number of lines of force, or in other words, the strength of the magnetic field produced by a current in a circuit is proportional to the current in that circuit. Hence in this case the law may run "*the induced electromotive force in any closed secondary circuit is proportional to the rate of change of current in the primary circuit.*"

74. **Coefficient of mutual induction.**—Let us write E_s for the

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* Let N be the number of lines of force passing through a circuit, then in the notation of the differential calculus the law becomes $E = M \frac{dN}{dt}$ where M is some constant depending on the geometry of the circuit.

electromotive force in the secondary circuit, and let C_p stand for the current in the primary. Let us indicate the rate of change of any quantity by writing its symbol with a dot over it, thus $\dot{C}_p$ will stand for the rate of change of C_p, and our law will be expressed in symbols thus

$$E_s = M\dot{C}_p.$$

Where M is a constant quantity depending on the geometrical relations of the two circuits. M is called the *Coefficient of Mutual Induction* and depends on the product of the number of turns in the two circuits and on their position with regard to each other, it is greatest for two given circuits when the secondary is so placed as to completely enclose the primary. M, the coefficient of mutual induction, will of course be increased by any means that increases the number of lines of force through the primary circuit for any given current.

Since the magnetic permeability of soft iron is very great, compared with that of air, an obvious method of increasing the number of lines of force is to place a soft iron core through the primary. This, however, has the drawback that owing to the sluggishness with which the iron becomes magnetised the secondary current is somewhat retarded behind the primary.

75. **Self induction.**—Since a current passing in a circuit sets up a magnetic field of force in the interior of that circuit we should expect to find indications of the inducing action of this field of force on the circuit itself. In fact we do see such indications in the appearance of a spark whenever a circuit containing an electromagnet or a large helix is broken. This action of an increasing or decreasing current on its own circuit is frequently spoken of as the *extra current*, but more correctly as an action of *self induction.*

There is no essential difference between the action of a variable current on its own circuit and on another, so that the self induction follows the same laws as mutual induction and we may write

$$E' = -L\dot{C}.$$

Where E' is the electromotive force in the circuit due to self induction and L is the coefficient of self induction, a constant belonging to the circuit, while $\dot{C}$ as before stands for the rate of change of the current. The negative sign is affixed because when the current is increasing the induced electromotive force tends to reduce it and *vice versâ.* Ohm's law then becomes for a variable current

$$E = CR - L\dot{C}.$$

The coefficients of mutual and self induction depend on the number of turns in the primary circuit considered, they may therefore be written with this number explicitly expressed thus, instead of M or L we may write nM' or nL' when n is the number of turns, and M' and L' are the true coefficients divided by the number of turns.

The equation for the electromotive force may then be written

$$E = CR - nL'\frac{dC}{dt} \text{ or } E_s = nM'\frac{dC_p}{dt}.$$

We may divide then in each case by the resistance of the circuits considered, and if the whole current that passes is required, we may integrate with regard to the time.

Thus, $Q = \int_0^\tau C\,dt - \frac{nL'C}{R}$ and $Q_s = \frac{nM'C_p}{R}$, when τ stands for the whole time of variation of the current, and therefore Q is the total number of units of electricity that have passed measured in coulombs if the current is expressed in ampères. The factor nC is here the important one, and is the product of the steady current into the number of turns, and may be expressed by one number which we call the "ampère turns" of the circuit or primary circuit considered. Now from these equations we see that since n is a number, the ratios L/R and M/R are of the dimensions of a time, and in fact, the ratio L/R is called the "time constant" for any circuit, and on it the time required to get up a steady current in a circuit depends.

The self induction current in a wire has often been compared to the inertia of a fly-wheel or of a current of water in a pipe such as is utilized in the case of the hydraulic ram, and the analogy is a very useful one and gives a very clear notion of its effects.

Methods of comparing coefficients of mutual induction and coefficients of self induction with each other or coefficients of self induction with those of mutual induction will be found in *Maxwell's* "Electricity and Magnetism," Vol. II., Chap. XVII., or in *Balfour Stewart and Gee's* "Practical Physics," Vol. II., Lessons lxxiii. to lxxv.

76. **Induction coil.**—We are now in a position to examine the Induction Coil or "Ruhmkorff" coil as it is often called. This is the instrument which is generally used at present for producing the so-called Faradic currents; a Faradic current being essentially a current of high electromotive force more or less rapidly interrupted and made again.* Such a current might be produced by a sufficient number of batteries and a mechanical interrupter, but it is much more easily produced by such an appliance as is named above.

Reduced to its simplest terms the Ruhmkorff coil consists of a short primary coil, of few turns of thick wire wound on an iron core (to increase the number of lines of force through it) with a long secondary coil of very many turns of well-insulated thin wire, wound round it and an arrangement for automatically making and breaking the circuit. In small coils this usually consists of a spring with an armature opposite the end of the iron core of the coil which presses against a platinum button and so completes the circuit; when the current passes the armature is at once attracted by the now magnetic core away from the button and the circuit is broken, only for the spring which is now freed from the attraction of the core to fly back and remake the primary circuit. Consequently with every make of the current in the primary circuit there is an electromotive force in the secondary circuit in the opposite sense to the current in the primary and with every break an electromotive force in the same sense as in the primary. The primary circuit however has considerable self induction of its own and the effect of this is to make the rise of current in the primary circuit more gradual than the fall, hence the electromotive force in the secondary is greater at the break than at the make. This difference is much increased by connecting a condenser (§ 32) with the ends of the primary coil. The effect of this is two-fold, in the first place it makes the break of the circuit more sudden by reducing the spark of self induction current that leaps across the gap in the primary at break and secondly it becomes charged by this "extra" current in such a sense that at make again the charge of the condenser tends to still further retard the rise of the primary current. Thus the currents at make in the secondary circuit being only caused by a low electromotive force are small and negligeable,* while those at break are produced with a high enough electromotive force to spark through a considerable air gap.

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* There is really an alternate current in every secondary circuit but as will be seen a Ruhmkorff coil is so arranged as to minimise the current at "make" and to leave that at break the important one.

It should be noticed also that these are in the same sense as the current in the primary.

The iron core is usually made of a bundle of soft iron wires insulated from each other to avoid loss of power by the induction of eddy currents in the core.

In coils for medical use it is usual to arrange some means of varying the co-efficient of mutual induction of the circuits so that the electromotive force in the secondary may be varied without altering the current in the primary. There are several ways of doing this. Sometimes the whole primary is made to slide in and out of the secondary or *vice versâ*, or sometimes the core alone is made to move in this way. Another method is to have a metal tube to slide over the core and so shield the secondary from the influence of the primary.* For a more full account of the induction coil, see § 119, Chap. V.

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* The total quantity of electricity is, however, the same at both make and break.

77. **Magneto machine.**—A few years ago a different form of so-called Faradic machine was commonly used. This was what would be now called a small magneto machine without a commutator.

The usual form consisted of a horse-shoe magnet with two soft iron rods wound with coils of fine wire mounted on a spindle to turn in front of the poles of the magnet so that the ends of the rods should be presented alternately to each pole of the magnet as the spindle was made to revolve. The coils were connected in series and the free ends were attached to metallic rings on the spindle so that the induced currents could be led off through springs or brushes rubbing on the rings. The spindle carrying the coils was made to revolve at a high speed by means of a handle and some sort of gearing. Then as the iron rods approached the poles of the magnet an electromotive force in one direction would be induced in the coils and as they receded from the magnet an electromotive force in the opposite direction would be induced, the currents led off to the electrodes would therefore be alternating and the electromotive force would depend on the speed of rotation of the spindle. There was generally a moveable soft iron armature attached to the magnet, by shifting the position of which the number of lines of force free to go through the coils and consequently the electromotive force in the coils for a given speed could be varied.

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* The explanation of the reason that a metal plate placed near the primary and not necessarily between it and the secondary shields the secondary was given by Sir W. Thomson in a Friday evening lecture at the Royal Institution.

The above described machine may be looked upon as a very primitive and badly designed form of dynamo, but since the magnetic field in which the armature revolves is given by a permanent magnet it is more usually called a magneto machine and the term dynamo is applied only to those machines in which the magnetic field is made by an electro-magnet. It would take up too much space and be out of place to give an account of any of the numberless forms of dynamo here. We must therefore be content to refer the student to such works as *S. P. Thompson's* "Dynamo Electric Machinery" in which a full account will be found of all the chief types of dynamo that are now in use.

78. **Practical note.**—In concluding this short account of the electric current we would remind the reader that there are few things so difficult to follow in all their vagaries as the connexions of electrical apparatus. Probably at first he will find the greatest difficulty in making the simplest piece of apparatus work. But he need not therefore jump to the conclusion that the battery or galvanometer or instrument that he is using is out of order, and that the instrument maker need be sent for to put it right. The connexions should first be examined and in all probability the fault will be found there. It is a very good thing to draw a diagrammatic plan of these and so check them off and make certain that all wires are connected up in the intended way. It is of course understood that the values of the various electromotive forces and resistances in the circuit have been so arranged as to give the required effect (§ 69). If things will not go right then, the resistances and

electromotive forces of the batteries should be taken and it will be quite time enough to apply to the instrument maker when something has been found to be wrong with these. A little intelligence in the application of theory will often save much cost and trouble in practice.

CHAPTER IV.

STATICAL ELECTRICITY. DESCRIPTION OF APPARATUS.

Historical. Description of instruments. Ramsden's machine. Holtz machine. Voss' machine. Wimshurst's machine. Carré's machine. Professor Lewandowski's machine. Conductors. The Leyden jar. Modes of application. The dry electric bath. Effects of a positive charge. Treatment by sparks. Treatment by shocks. The brush discharge. Static Induction.

79. **Historical.**—In the early applications of electricity to medicine the statical apparatus was the only form used because it was the only one known. For many years after the discoveries of *Galvani* and *Volta* statical electricity still remained in exclusive possession of the field of electro-therapeutics. The number of accessories required, the expense and cumbersomeness of the machines, and the unpleasant shocks employed as the chief mode of its administration have prevented its frequent use in the treatment of disease; but no electrical department of a hospital would be complete unless it were provided with an apparatus for the treatment of patients by statical electricity.

As has been mentioned in a former chapter, *Jallabert* in France (1748) was one of the first to apply statical electricity to medicine. He was followed in 1749 by the *Abbé Nollet.* In 1745, *De Haen* in Germany published a number of cases of spasmodic, paralytic and other nervous affections cured by electricity.

In 1758, *Benjamin Franklin* relates that in consequence of the cures reported to have been made in Italy and Germany, a number of paralytics were brought to him for treatment from different parts of Pennsylvania and the neighbouring provinces.

In 1759, *John Wesley*, the great divine, collected and published in a book called "The Desideratum," the details of a vast number of cases treated by electricity. Among them he mentions that electricity accelerates the passage of calculi through the ureters. He also relieved tertian and quartan fevers, and hysteria.

In 1773 and 1778 *Manduyt* published two works on statical electricity.

In 1777 *Cavallo* published in London a complete treatise on electricity in theory and practice, with original experiments.

In the next year there appeared the thesis "Electricitate et Operatione,"* by *Dr. Robert Steavenson* of Newcastle, which has been already alluded to.

In 1783 *Wilkinson* also wrote upon the subject. Then came the long lists of cases in the Guy's Hospital Reports treated by frictional electricity by *Addison* (1837), *Golding Bird* (1841 and 1847) and by *Sir William Gull* (1852-3); and later by *Dr. Radcliffe* in the National Epileptic Hospital.

More recently (1873), *Dr. Arthuis* of Paris has revived the treatment by statical electricity and has published a book on its use in nervous and rheumatic affections. This application of electricity has been greatly used by *Professor Charcot* and his pupil *Dr. Vigouroux* at the Salpêtriere; and recently in this country attention has been paid to the subject by *Dr. Tibbits* and by *Dr. McClure*.

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* Reprinted by *Messrs. J. and A. Churchill* in 1884.

80. **Description of instruments.**—The first form of electrical machine was a large sulphur ball which was excited by one hand as it was revolved by the other. It was made by *Otto von Guericke* of Magdeburg in 1672. Subsequently resin was used and then a glass cylinder. instead of the sulphur ball. In 1740 *Winckler* excited the glass by means of horse-hair cushions covered with silk instead of the hands.

81. **Ramsden's machine.***—In 1760, Ramsden substituted a circular glass plate for the cylinder, and his apparatus is still in common use. In the Ramsden machine electrical separation is produced by the friction of the glass disc between two sets of amalgamated rubbers. The glass plate is fixed on an axle and made to revolve by means of a handle, and the rubbers adjusted by screws are made to press lightly against it. The glass is found to be positively electrified and the rubbers negatively. The rubbers, however,

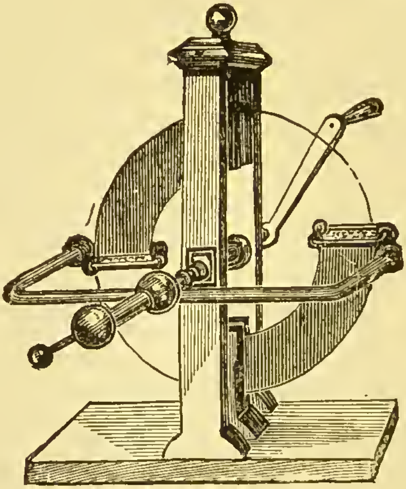

FIG. 21.—Ramsden's machine.

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* *See* note § 14.

are kept at zero potential by an earth connection, usually a metal chain. Partially encircling the glass disc are two brass rods one on either side provided with a series of sharp points on the surfaces opposite the glass. These brass rods are connected with two large metallic cylinders which are called the *prime conductors.* The prime conductors are supported on rods of glass covered with shellac varnish, and are united by a smaller brass rod. In the language of the two fluid hypothesis, when the machine is at work the positive electricity on the glass disc decomposes by induction the neutral electricity of the prime conductor. The induced negative electricity is discharged by the sharp points or combs on to the glass disc, and so neutralizes its positive charge, leaving the prime conductor positively charged. If the finger be now approached to the prime conductor, a spark passes to it and the conductor is discharged, to be again charged as the machine is worked.

82. **Influence machines.**—In most modern machines induction is more directly utilized and on this account they are often known as influence or induction machines. In 1865 *Holtz* of Berlin, invented a machine which, when charged from an electrophorus would continue to produce electrical separation by induction. This form of machine proved to be much more powerful than the best frictional machines. About the same time a similar machine to that of *Holtz* was invented by *Toepler.*

83. **Holtz machine.**—The best known form of the Holtz machine (fig. 22) consists of two glass plates, A B, one having a diameter larger by two inches than the other. The larger plate is fixed but the smaller one is made to rotate very rapidly by means of a cord and pulley, its axle passing through a hole in the centre of

the larger plate. The plates are quite close together but do not touch. In the fixed plate are two windows, *a*, *b*, diametrically opposite to each other. Two pieces of paper called "field plates" are glued on to the fixed plate, one above the window on the left side and one below the window on the right. They are on the surface

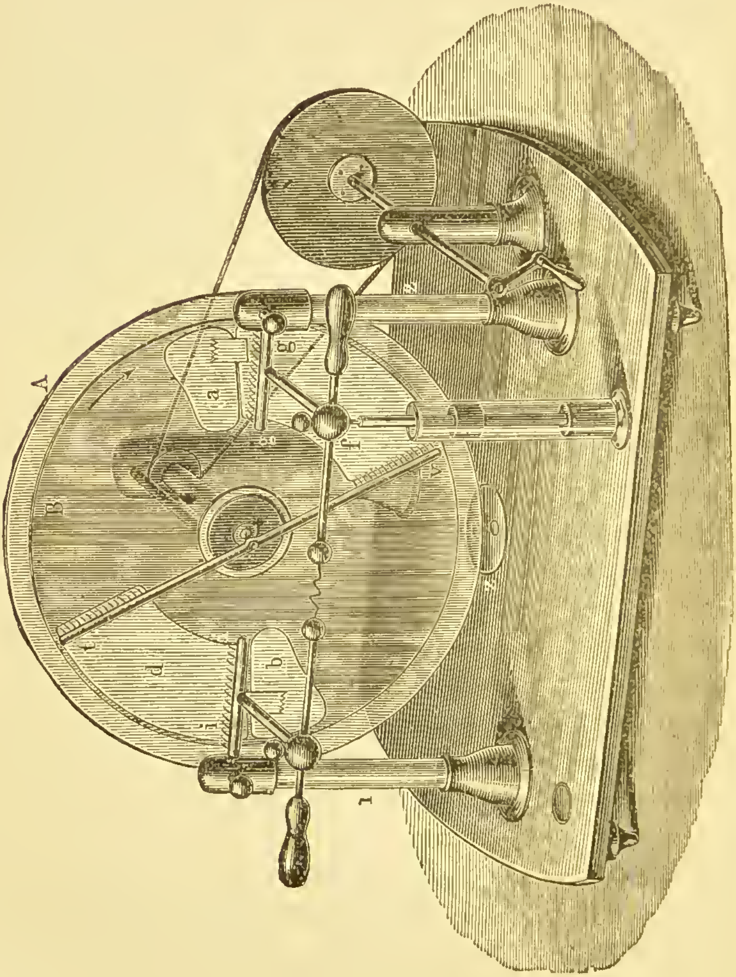

FIG. 22.—Holtz machine.

of the plate away from the revolving one. A tongue from each of these pieces of paper, protrudes through each aperture and nearly touches the revolving plate. The plate is rotated in an opposite direction to that in which the tongues point. Near the outside of the revolving plate are two brass combs, *g*, *i*, supported by two brass rods with knobs, *f*, forming the prime conductor. Two smaller brass rods, with ebonite handles, and two small brass balls act as electrodes and slide through the knobs at their other ends. These smaller balls can be approximated and withdrawn from each other by means of the handles and in that way the length of spark can be regulated. The rod *t* V is called the neutralising rod and is said to make the machine less likely to reverse. Before starting the machine one of the field plates must be charged from an electrophorus. The moveable plate is then rotated rapidly and a series of sparks will pass between the electrodes. The electromotive force of a Holtz machine is said to be nearly equal to 52,000 volts and the resistance equal to 2,810 megohms when the moveable plate is rotated 120 times a minute, and equal to 646 megohms when the rotations are 450 a minute.

84. Subsequently a self-exciting machine was invented, known as the Voss machine. It is still the favourite in Germany, although in England Wimshurst's machine is preferred. It is somewhat similar to the Holtz and it is said to act well in all weathers. This is not quite correct for the English climate, but still it is less easily affected by the weather than are the frictional or combined frictional and induction machines. The discharge from even the smallest Voss has been compared to that obtained from a powerful induction coil and battery. The labour required for revolving the plate is light, but like many of these induction machines it has the ob-

jection that the poles are apt to reverse when the electrodes of the machine are separated beyond sparking distance.

85. **The Wimshurst machine.**—The Wimshurst self-exciting machine is an improvement on the Voss in that it is more readily excited, and will work in almost any weather. It is also claimed for it that its polarity will not reverse even when the poles are separated beyond sparking distance.* It consists of two circular glass discs (or any even number up to twelve), mounted upon a fixed horizontal spindle in such a way that they rotate in opposite directions at a distance apart of not more than one-eighth of an inch. Each disc is attached to the end of a hollow boss of wood, or of ebonite, upon which is turned a small pulley. This is driven by a cord or belt from a larger pulley, of which there are two attached to a spindle below the machine, and which is rotated by a winch handle, the difference in the direction of rotation being obtained by crossing one of the belts.

Both discs are well varnished, and attached to the outer surface of each there are radial sector-shaped plates of tin-foil disposed around the discs at equal angular distances.

The two sectors situated on the same diameter of each disc are twice in each revolution momentarily placed in metallic connection with one another by a pair of fine wire brushes attached to the ends of a curved rod, supported at the middle of its length by one of the projecting ends of the fixed spindle upon which the discs rotate, the sector-shaped plates just grazing the tips of the brushes as they pass them.

The position of the two pairs of brushes with respect to the fixed collecting combs and to one another is variable, as each pair is capable of being rotated on the spindle through a certain angle ; and there is, as in the case of the collecting commutator brushes of a dynamo, one position of maximum efficiency. This position in the machine appears to be when the brushes touch the discs on diameters situated about 45° from the collecting combs, and 90° from one another.

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* *Gray* "Electrical Influence Machines," 159.

The fixed conductors consist of two forks furnished with collecting combs directed towards one another, and towards the two discs which rotate between them, the position of the two forks, which are supported on ebonite pillars, or in the latest pattern on Leyden jars, being along the horizontal diameter of the disc. To these collecting combs are attached the terminal electrodes whose distances apart can be varied.

The presence of these collecting combs appears to play no part in the action of the apparatus except to convey the electric charge to what may be termed the external circuit, for the inductive action of the machine is quite as rapid and as powerful when both collectors are removed and nothing is left but the two rotating discs and their respective contact or neutralising brushes, the whole apparatus bristling with electricity and if viewed in the dark presents a most beautiful appearance, being literally bathed with luminous brush discharges.

With a machine having plates 17 in. diameter and of the newest design (fig. 23) having two or four Leyden jars as shown in the drawing, there is produced under ordinary atmospheric conditions a powerful spark discharge between the electrodes, even when they are separated by a distance of 4 or 5 inches, and these discharges take place in regular succession at every two and a half turns of the handle. The machine is very efficient and perfectly self-exciting, provided there are sufficient sectors, generally requiring neither friction nor any outside electrification to start it, and this is one of the most remarkable features of the apparatus, for under ordinary conditions the machine works at its full power after the second or third revolution of the handle. It has been suggested that this initial charge is obtained from the friction of the air, and that chiefly between the plates, but nothing certain is known about it. Whether, however, the initial charge be derived from air friction or not, its generation is a point of very great theoretical interest, especially in the remarkable experiment referred to, in which both conductors are removed and most brilliant electrical effects are produced when the apparatus consists simply

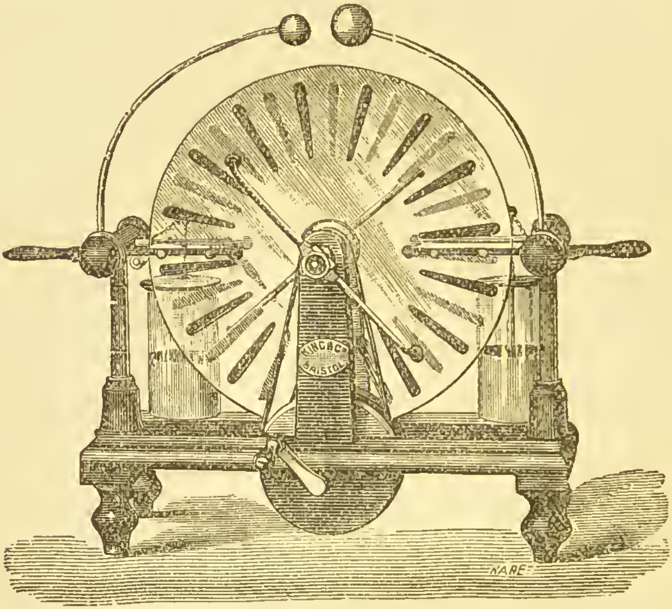

FIG. 23.—Wimshurst machine.

of two discs rotating in opposite directions, with no fixed conductors except the light conducting brushes.*

When the glass plates are very large they are apt to split. This is a very serious matter, as they are costly, so a modification of the Wimshurst machine has been made with ebonite plates which are said to be far superior to glass in all respects, give a much more powerful current of electricity and are not liable to breakage during transit or use and can be safely driven at a very high speed. There is, however, a grave objection to the use of ebonite as it gradually deteriorates on the surface and loses its insulating properties.

86. **Carré's machine.**—An apparatus now commonly used for medical purposes, is Carré's machine, which is a combination of a frictional and an induction machine. It is very good and works well in the winter but is much more difficult to excite than a Voss or Wimshurst machine. Carré's machine consists essentially of a revolving ebonite disc and a glass disc frictionally excited which acts as a field plate and supplies the initial charge which is multiplied by the revolving ebonite disc. Referring to the figure it is seen that when the handle is turned it rotates the glass disc which is mounted on the same axle between the rubbers this being positively excited acts inductively across the ebonite disc on the collecting comb E which discharges negative electricity on to the ebonite disc and at the same time it, and the conducting arm in connection with it become positively charged. In the meantime the ebonite disc which is caused to rotate at

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* The above is an abridged description of the machine which appeared in "Engineering," January, 1883. A full account of induction machines will be found in a little book by Mr. J. Gray, entitled, "Electrical Influence Machines."

a high speed carries its negative charge round to the collecting comb F which is connected to the prime conductor. This then becomes negatively charged and by the action of the points on the combs E, F the negative charge on the disc is neutralized. This action is continuous and after a few turns of the handle sparks can be drawn or Leyden jars charged from the prime conductor. The action of the machine is helped by placing a glass plate close in front of the ebonite disc between the combs E and F. Probably this merely prevents the dissipation of the negative charge as it is carried round from E to F. The rubbers must of course be connected to earth.

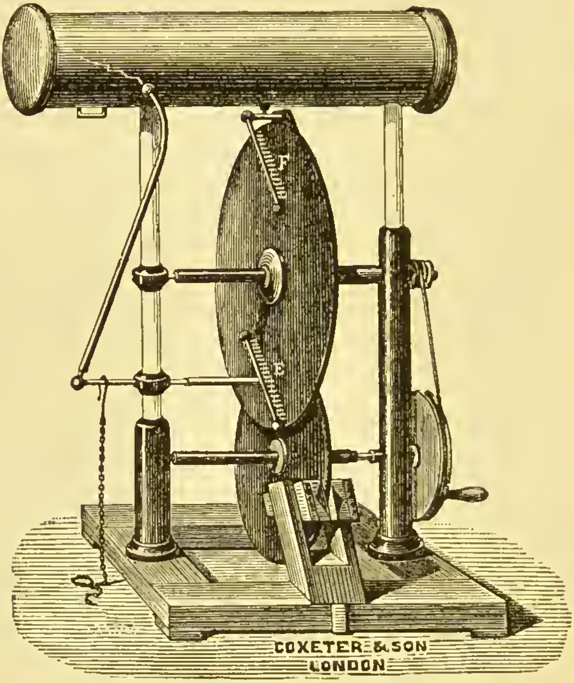

Fig. 24.—Carré's machine.

Before use every part of the machine should be thoroughly dry and warm. If the machine does not work well the plates should be rubbed with a dry silk handkerchief and the cushions warmed before the fire. Care should be taken that there are no sharp points or angles near the machine to discharge the prime conductor (cf. § 29). The atmosphere should be dry and in this country it is best to place the machine near a fire or stove.

The machines work best in dry frosty weather. The qualities ascribed to electrical machines by continental writers are often not found to be possessed by them when worked in this country. The atmosphere in England is usually so charged with moisture that the conditions under which these machines are worked here are so entirely different that they have to be tried before any opinion can be formed as to their merits.

87. **Lewandowski's machine.**—Recently an influence machine has been brought out by Professor Lewandowski of Vienna, on the same principle as Clarke's well known electric gas lighter. The action takes place inside a closed cylinder of ebonite and is therefore not so easily affected by the weather, but the supports of the conductors are of course as subject to atmospheric influences as those of other machines. Should this machine maintain its character for not reversing easily, it is likely to become very useful and to be frequently employed on account of its certainty as a generator. As, however, it is made of vulcanite it is liable to deterioration from surface decomposition of the material.

The two vertical iron supports *a* a_1 and *b* b_1 (fig. 25) are screwed to a wooden frame *Ra* Ra_1 and joined together at the top by the vulcanite rod *ab*. These two uprights support three axles *ef* W_1 and W_2 which are parallel to each other. The axle *ef* is fixed and made of steel. Upon this axle are two tubes of vulcanite to which are attached the drum-like cylinders T T_1, the

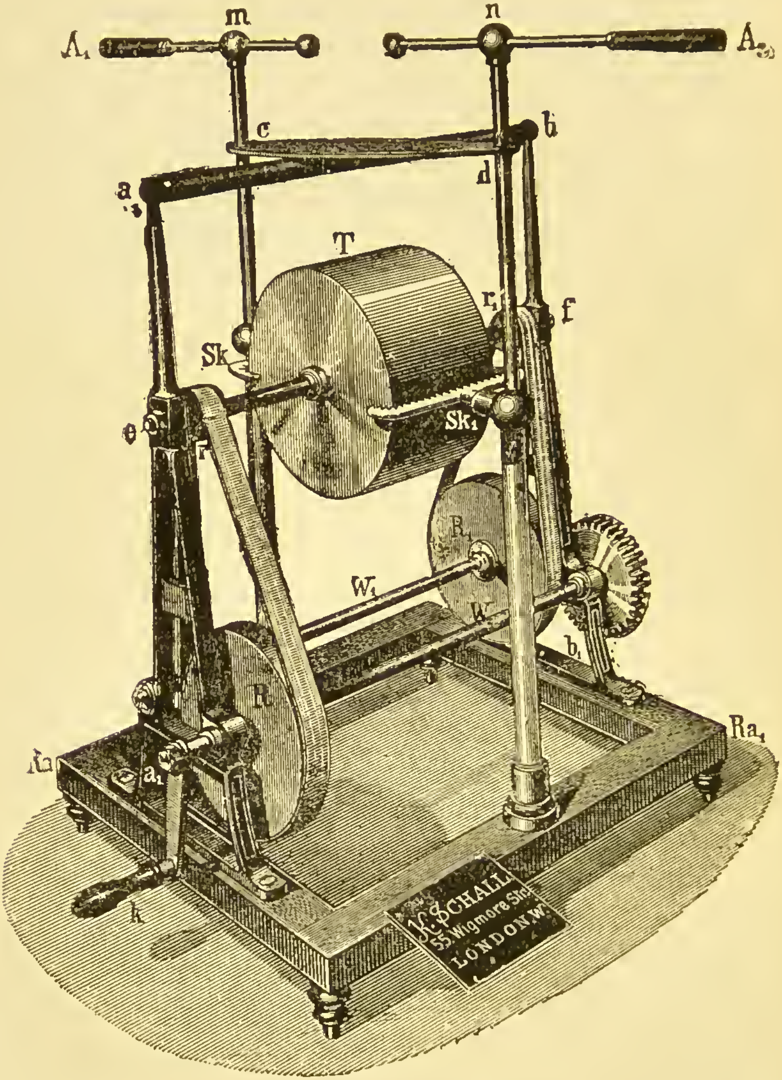

Fig. 25—Lewandowski's machine.

ends of the tubes constitute the two pulleys r r_1 (figs. 25 and 26). The drum-like cylinders are in the centre, one within the other, T and T_1. The pulley r_1 is connected with the internal drum and the pulley r with the external one in such a manner that they rotate in opposite ways.

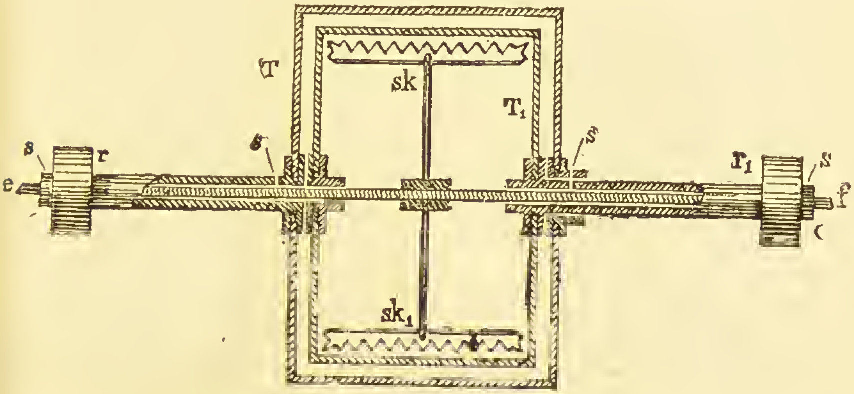

FIG. 26.—Lewandowski's machine. Section through the ebonite cylinders.

The two lower axles W_1 W_2, each carry a large pulley R and R_1. These pulleys are respectively united by means of endless straps to the superior pulleys r r_1. The axle W_2 is provided with a handle K and a toothed wheel which rotates W_1. When turned the two drums revolve in opposite directions on account of the action of the toothed wheel. The frame Ra Ra_1 also carries two uprights the lower parts of which are made of glass and the upper of metal; these terminate in metallic knobs m n. In the middle of these supports are two other knobs Sk Sk_1 each with a collecting comb in close proximity to the external drum, and on opposite sides of it. The fixed steel axle ef carries a vertical metal rod inside the inner drum. Through the knobs m n the conductors A_1 A_2 can be moved to and fro in a horizontal direction. To excite the machine it is necessary when the knobs of the conductors A_1 A_2 are in contact, to turn the handle *K* and at the same time to touch the external drum with an electrically excited body midway between the two collecting combs *Sk* Sk_1.

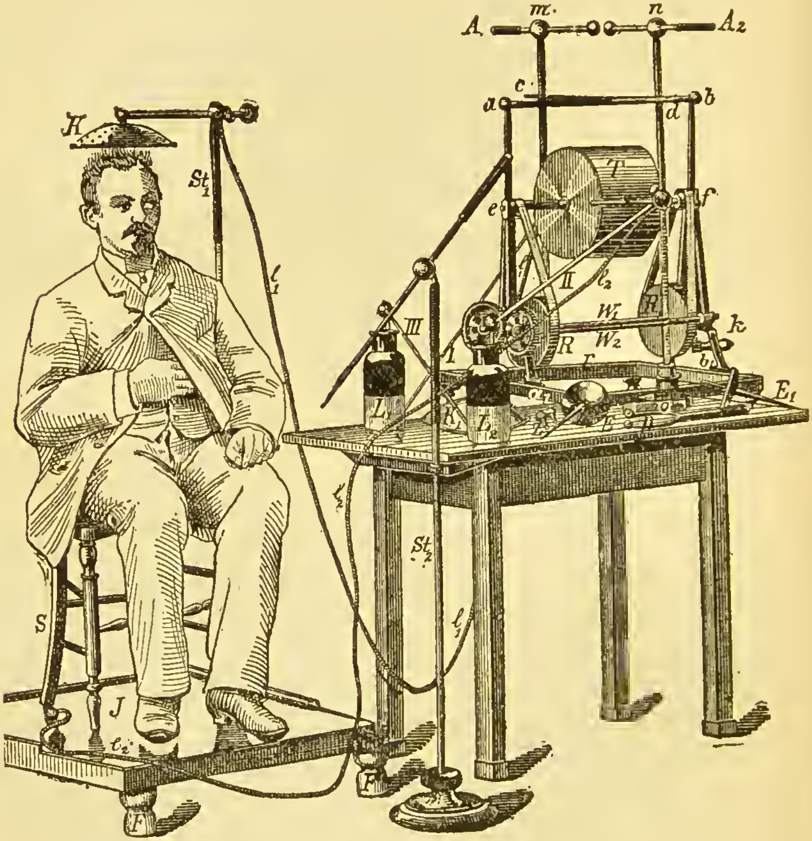

FIG. 27.—Lewandowski's machine in use.

Fig. 26 shows the spindle *ef* and the drums enlarged. Fig. 27 represents the machine in use. The cap *K* is provided with points. There are several other accessories on the table including two Leyden jars. The patient's chair is placed on a platform *J* insulated by four porcelain feet *F F*. The insulated cords l_1 l_2 connect the collecting combs *Sk* Sk_1 with the platform *J* and with the electrodes.

88. **Conductors.**—The means of connecting the patient to the electrical machine is of some importance especially in this country where the air is usually so charged with moisture which readily condenses on the insulator. It has been found that a metallic chain offers so many irregularities and points that it tends to the dissipation of the charge; and flexible insulated cords composed of metallic threads twisted round a cotton core, as used with galvanic and faradic apparatus also bristle with points. The chain is a very useful conductor for connecting the rubbers to earth and is usually used for that purpose, but the charge which we wish to communicate to the patient can be best conveyed by a smooth metallic tube having a hook at one end to connect it with a loop on the prime conductor, and turned into a handle at the other end for the patient to grasp. It is also found best to let the patient take hold of the handle and not to let it simply rest on the insulated couch or stool as is often done.

89. **The Leyden jar.**—*The Leyden jar* (fig. 5, p. 36) was discovered in 1749. It consists of a glass jar with rather more than the lower half covered both inside and out by tin-foil. It is closed with a stopper pierced by a brass rod which ends in a knob two or three inches above the top of the jar and on the inside there is a chain attached which makes metallic connection with the inner lining of tin-foil. The jar is charged by connecting the inner coating with the prime conductor of the machine and the outer coating to earth, or, in the case of an influence machine, to the other electrode. The inner coating is thus raised to the potential of the

prime conductor while the outer is at zero potential. In consequence of the large capacity of the jar (§ 30 and 32) a considerable charge is required to effect this. To discharge the jar it is necessary to bring by a conductor the external coating into metallic proximity with the internal one, viz., within sparking distance. A bright flash is seen and a slight report heard as the jar is discharged. The instrument used to discharge a Leyden jar is called a *discharger* (fig. 28) and consists of two curved pieces of stout brass wire hinged together, each section being provided with a glass handle. By this means a Leyden jar can be discharged either directly or through a patient without the operator receiving a shock.

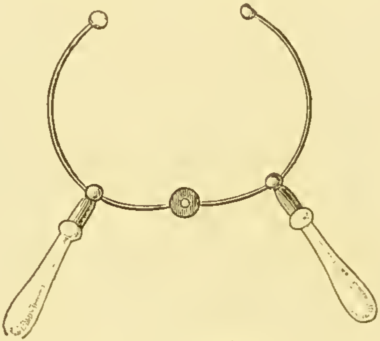

FIG. 28.—Discharger.

There are other instruments used for administering statical electricity that are called *Excitors.* They are of different shapes and sizes according to the effect it is wished to produce. The most simple and frequently used is a small brass rod ending in a brass ball (fig 29)

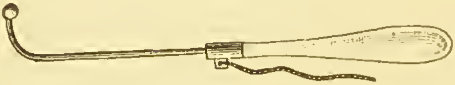

FIG. 29.—Excitor.

and having a glass handle. On the brass just before its junction with the handle is a ring or loop to which is attached a brass chain or metallic insulated cord. The brass chain can be allowed to touch the ground or can be attached to one of the conductors of the statical machine according to circumstances. It is also necessary to have a ring or crook (fig. 30) with an insulated handle, or a glass rod, by which the metallic chain can be kept from coming too close to the operator.

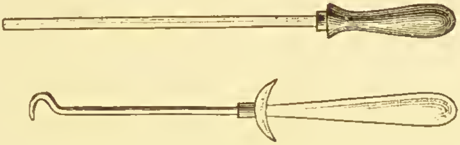

FIG. 30 —Insulated supports.

90. **Modes of application.**—The methods of application of statical electricity are the same now as they were when *Dr. Steavenson* of Newcastle-on-Tyne wrote on Medical Electricity in 1778 and are fully described in his book referred to above.

91. **The dry bath.**—The patient may be treated by insulation, or the so-called dry electric bath. This is carried out by placing the patient, who may be fully dressed, on an insulated couch or chair and connecting him either by metallic rod or chain to the conductor of a frictional machine. The machine is then set in motion and the patient is charged either with positive or negative electricity according to his condition and requirements. Equilibrium is then allowed slowly to re-establish itself through the atmosphere. As soon as the machine is set in motion, the patient feels in a curious nervous condition difficult to describe. His hair feels inclined to stand on end and on his face

he feels a slight sensation as if lightly touched by gossamer. Perspiration is induced and all the natural secretions of the body are encouraged and increased. The dry electric bath is given for varying lengths of time. In the practice of different physicians it has ranged from 10 minutes to three or four hours. When continued for the more lengthened periods the patient has to be recharged from time to time by a few additional turns of the machine. It is probable that from half an hour to an hour is the best time to keep the patient under the influence of the charge. The dry electric bath should be repeated daily for the first week or ten days, then every other day or occasionally as the condition of the patient requires. At the Salpêtrière in Paris, where this treatment is much in vogue, insulating couches are used large enough to hold many patients at once. They are charged from huge Wimshurst machines driven by gas engines. See *Dr. Maclure's* little book "Statical Electricity in Medicine."

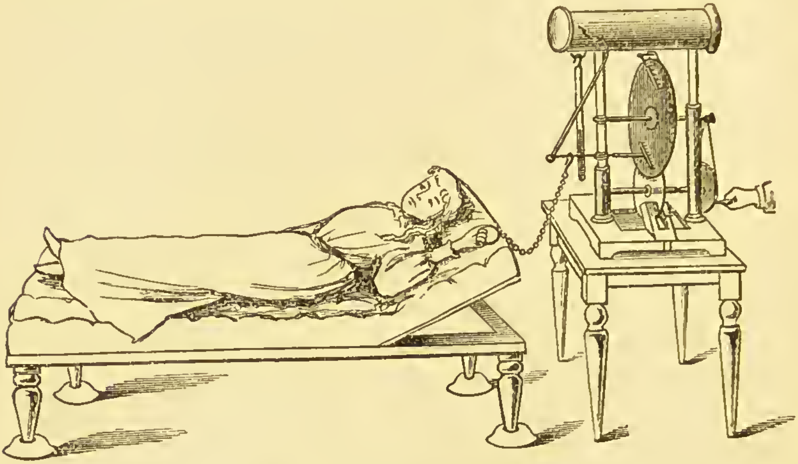

FIG. 31.—Dry Electric Bath.

92. **Effects of the positive charge.**—The *positive*

charge has been found useful in general debilitated conditions of the system, such as old age, debility during convalescence from acute illnesses, after confinement or excessive lactation, general prostration from anxiety and over-work, many mental states accompanied by a depressed condition of the system, such as some forms of hysteria, melancholia, and nervous insomnia ; we have also met with encouraging results in the treatment of spasmodic asthma. The opposite condition, namely a *negative* charge, has on several occasions been known to induce an attack of the disease.* The negative charge produces a condition of the body as of utter prostration, similar to that produced by blood-letting, and similar to those conditions that accompany great prostration from severe illness or other cause when the normal irritability of the nerves has deteriorated, and the natural nerve currents are diminished and the nerves are in a condition of decreased excitability. Many of the good results formerly derived from the use of statical electricity were probably misunderstood and did not depend upon the shocks given to the patient but to the preliminary charging, for as a matter of fact the patients were generally charged positively, since Ramsden's machine, then most frequently used, would only produce a positive charge when used in the ordinary way.

93. **Treatment by sparks.**—A second method of using statical electricity is by sparks. Sparks are taken from a patient in two ways called respectively the *direct* and the *indirect*. In the direct method the patient is placed upon an insulated chair or bench and connected with one electrode of the machine, the excitor is connected with the other (fig. 32). The spinal

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* *Vide* "Electricity and its Manner of Working in the Treatment of Disease," *J. and A. Churchill*, London, 1884, p. 38.

column or part to be treated is laid bare, and when the patient is charged, an excitor (fig. 29) is brought near to the patient and a spark is immediately seen to pass between the two. Several contrivances are sold by instrument makers (*e.g.*, fig. 33) for regulating the length of spark taken. But these are unnecessary when an influence machine is used, as the maximum length of spark can be exactly controlled by the space between the discharging electrodes of the machine, for these are always capable of being separated or approximated to regulate the sparking distance. In this way it is often possible to draw from the patient a spark of two, three or

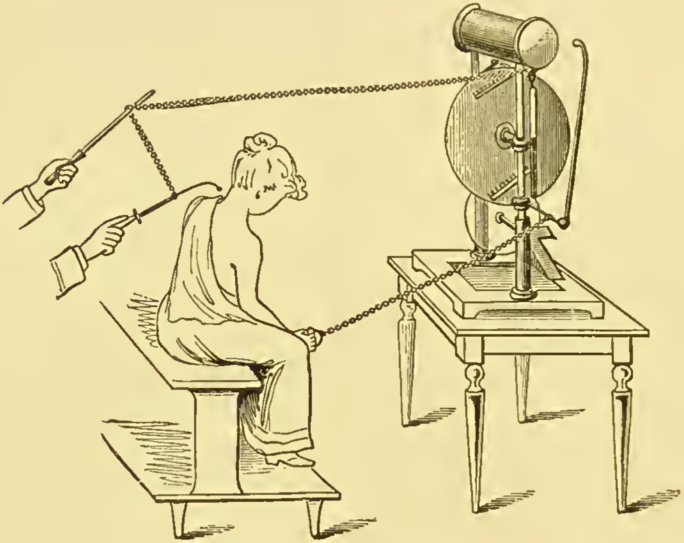

FIG. 32.—Treatment by sparks.

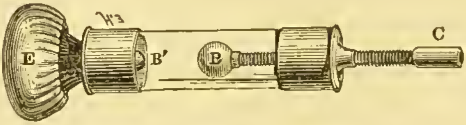

FIG. 33.—Spark regulator.

four inches long. Differences in the nature of the spark can be produced by varying the shape and size of the excitors.

A pointed excitor, for obvious reasons (cf. § 29) gives a smaller spark or even only a brush, and the suddenness and violence of the spark can also be increased by an increase in the size of the brass balls used. For the indirect spark, one conductor of the machine is connected with the ground, and the patient on the insulated support is connected with the other conductor. The wire from the excitor (or electrode) is then also allowed to touch the ground or is connected with a gas or water-pipe in the room. By this means less vigorous and irritating sparks are taken from or passed to the patient.

It may be as well at this point to call attention to the nature of the Leyden jar discharge. We are apt to consider the discharge as taking place from one specified point of a circuit to another, but this is quite incorrect. The real state of affairs is one of oscillatory current sparking across the air gap in the circuit, so that the spark cannot be said to pass only from one point to another. There are always several oscillations in a spark discharge, the period of these is determined by the nature of the circuit, and depends chiefly on two things, namely, the capacity of the jar and the time constant of the circuit through which the discharge takes place, an increase in either of these will cause an increase in the time of the oscillations. To have some idea of the rate of the oscillations, we may remember that, as has been lately demonstrated by *Hertz*, electric radiation is propagated with the velocity of light, namely about 3×10^{10} centimetres per second. It would be easy to arrange a jar and circuit from which would be emitted waves of one metre in length, the number of oscillations per second in such a case would be 3×10^5 say three hundred millions, an almost inconceivably great rapidity of oscillation.

Comparing great things with small we may draw an analogy between this and the faradic discharge which may be looked upon as a slow oscillatory discharge, probably not often exceeding two hundred and fifty oscillations per second. These discharges produce somewhat similar physiological effects, but the latter are the more painful perhaps because of the greater magnitude of the oscillatory currents involved.

94. **Treatment by shocks.**—Shocks are administered by means of the Leyden jar. This is charged from the prime conductor of an electrical machine in motion;—negatively when the Carré machine is used. A discharger is laid in contact with the external coating and then made to touch that part of the patient through which it is wished that the shock should pass, and the knob of the jar, in connection with the internal coating, is approached to the patient on the opposite side of the trunk or limb; when within a varying distance of the skin—half an inch or less according to the potential of the charge—a spark is seen to pass and the jar is discharged. An unpleasant shock is given, and a slightly raised spot with congested areola, similar to a flea bite, is left for a short time. A more manageable way of discharging the Leyden jar is to connect it with an insulated brass excitor (fig. 34) by means of a flexible metallic cord encircling the external coating of the jar above where it is held by the hand for the purpose of charging. The knob of the excitor may be made to touch the patient at the part it is wished to treat and the jar when charged brought near to the patient. Immediately the knob is near enough for the

spark to pass, the jar will be discharged. The treatment by shocks is only suited for local applications.

95. **The brush discharge.**—The electric wind, breeze, current, brush or souffle, are all terms given to that method of administering static electricity first proposed by *Dr. Steavenson* in 1778. The following is the description that he gives, translated from his Latin thesis* :—" Whilst I was thinking over the property of sharpened conductors, that is their power of suddenly drawing the electric fluid which has become accumulated out of bodies silently and without a spark, a fourth method of applying it, which promises to be advantageous, occurred to my mind, and which, to distinguish it from the others, I would call the *pencil method.* It is very well known that pointed instruments strongly attract the fluid when once excited ; if therefore to an insulated human body, unduly charged with electric fluid, a pointed conductor be applied, the superabundant fluid

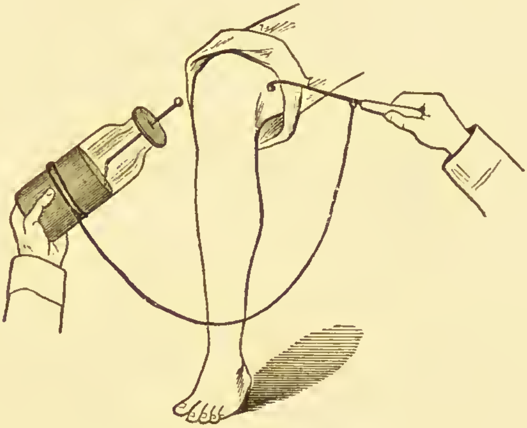

FIG. 34.—Application of shocks.

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* By the *Rev. F. R. Steavenson*, late Classical Scholar of Emmanuel College, Cambridge.

will be drawn out without a shock, and at the same time without causing pain from this part, in the form of a luminous pencil; whereby the volume and speed of the fluid as it passes through whatever part we desire may be greatly increased, and if we enlarge the space through which the fluid makes its escape it will only be necessary to increase the number of points." This method has been adopted under one or other of the names previously given by most of those who have made use of statical electricity for curative purposes. The electric wind or breeze can be produced by bringing a pointed excitor near to an insulated patient who has been charged with electricity. The sharpened excitor may be made of brass or wood. When the comparatively blunt wooden point is used the breeze is not so strong as with the sharper brass one. A crackling, hissing sound is produced and in the dark a luminous brush of light is perceptible. The patient feels a pleasant sensation as of a cool draught of wind playing upon the part under treatment. When the more vigorous souffle is required, an electrode is used, having numerous points fixed upon a metallic disc (fig. 35) and provided with an insulated handle. The breeze or souffle is used for the relief of pain, in neuralgia, the lightning pains of locomotor ataxy, and other painful affections. It is said to have a marked sedative effect.

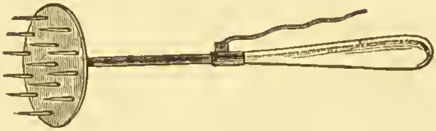

FIG. 35.—Brush electrode.

96. **Static induction.**—*Dr. McClure* mentions an additional use to which static electricity can be applied,

which has recently been discovered and by which muscular reactions can be tested as with the faradic machine, and with less pain. He describes the method as follows :—" A small Leyden jar is attached by means of a hook to each conductor of the static machine. To the outer coatings of these jars are attached a pair of ordinary conducting cords with moistened electrodes. The poles of the machine are now separated very slightly, giving a short spark; during the passage of each spark an induction current is sent down the cords and received by the patient, who need not be insulated; nerve and muscle may thus be acted on in exactly the same way as in the application of faradism. The strength of the current is determined by the size of the jars, and the amount of separation of the poles of the machine. In the machine of Carré the poles must almost touch and the jars must be very small—of the capacity of about 4 or 6 ounces. I believe we have in the static induced current a means of producing muscular contractions when the strongest bearable application of faradism fails."*

This quotation from *Dr. McClure* suggests a very interesting method of examining the muscles and one less painful than the usual method of applying the faradic current. From the last part of § 93 it will be seen that the two methods are analogous, since the arrangement suggested by *Dr. McClure* produces oscillatory currents similar to those considered there. Those who have had much experience of the distress produced in young children by the electrical examination of their muscles in the usual way will gladly welcome any plan less terrifying to the patients than faradic currents are.

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* "Static Electricity in Medicine," by *H. McClure M.D.*, London, *H. Renshaw*, 1889.

CHAPTER V.

BATTERIES AND APPARATUS.

Essentials of a good battery. Electromotive force of cells. Capacity of cells. Polarization. Depolarizers. Smee's battery. Bichromate battery. Daniell's battery. Grove's and Bunsen's batteries. Leclanché battery. Chloride of silver battery. Oxide of copper battery. Dry batteries. Sulphate of mercury battery. Latimer Clark's standard cell. Stöhrer's battery. Accumulators. Table of batteries. Choice of a battery. Care of a battery. Use of electric lighting currents. Transformers. Medical induction coils. Primary and secondary currents.

97. **Essentials of a good battery.**—Numerous modifications of *Volta's* original cell have been from time to time proposed with the object of improving it in one way or another. There are three objects to be aimed at in striving to effect such an improvement, first, the electromotive force of the cell should be as high as possible, secondly, the quantity of current, or the density of current per square centimetre of active surface of the plates must be great, and thirdly, the cell must be constant, *i.e.*, it must be capable of giving a large current without any fall of electromotive force due to polarization (see § 59). There are also other matters to be attended to, *e.g.*, there should be no action in a cell when the circuit is broken, but this belongs rather to the management of batteries than to our present subject.

98. **Electromotive force of cells.**—The limit of electromotive force that can be obtained from a single cell is soon reached, since, as shown in § 39, it depends

almost entirely on the contact electromotive force between dissimilar substances (metals or metalloids). We must note here that in a cell where the poles are say zinc and platinum, the contact electromotive force is really that between zinc and platinum, although the zinc and platinum do not touch each other throughout the circuit. We may, however, look on it as made up of the contact electromotive force between the zinc plate and the copper connecting wire, plus that between the copper connecting wire and the platinum plate. Full tables are found in electrical text-books of metals arranged in order, the most electropositive at the head of the table, the most electronegative at the foot. An abbreviation of such a table* is the following:—

Electropositive.
Sodium.
Magnesium.
Zinc.
Iron.
Lead.
Copper.
Silver.
Mercury.
Platinum.
Carbon.
Electronegative.

This order is given for the elements in contact in presence of dilute acid; under other circumstances the order is liable to alteration, and this fact is a serious difficulty in the way of the "contact" theory of electromotive force which has been taken as a working hypothesis for our purposes. We may refer the reader again to *Dr. O. Lodge's* "Modern Views," Chap. VI.

It follows that the battery with the greatest electromotive force would be that, the poles of which consisted of the two materials at the extreme ends of the table, and most of the improvements in batteries made with the object of increasing the electromotive force have been by substituting metals further down the table for the copper pole of *Volta's* cell. Thus in *Smee's* cell we find a platinized silver plate is used for the positive pole, in *Grove's* battery a platinum plate, while in *Bunsen's* carbon is used. Until, therefore, it becomes practicable to use magnesium or sodium instead of zinc, we can hardly expect to obtain primary batteries of higher electromotive force than those in which zinc and carbon poles are used. These batteries when working to the best advantage have an electromotive force of something under two volts. That of a *Bunsen's* cell is from 1·8 to 1·9 volts.

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* *Miller's* "Chemistry."

As will be seen in the description of storage batteries a positive plate of peroxide of lead affords a means of getting a high electromotive force, and the combination of it with a zinc negative plate has been found to yield very satisfactory results; one form of such a combination has lately been introduced under the name of the *Lithanode* battery, and it is said to have an electromotive force of 2·5 volts.

99. **Capacity of cells.**—Under the second head there is not much to be done in improving batteries; the internal resistance should of course be kept as low as possible by making the plates approach as near one another as may be, so that the current shall have to pass across the least possible thickness of electrolyte. The plates of the battery should be large and should be kept clean, and the zinc must be pure and homogeneous, or at least well amalgamated with mercury to prevent local currents from differences of hardness and purity, for

these give rise to electromotive forces between parts of the zinc and cause local action and wasting. In one modern type of cell the zincs are made of an amalgam of zinc and mercury fused together and cast into the required shape. This is said to work well.

100. **Polarization.**—There is much more scope for improvement in batteries as regards the third point, and much attention and ingenuity have been concentrated upon securing constancy of current and absence of polarization in batteries. This is easily seen to be an important matter, for nearly all batteries undergo a rapid fall of electromotive force when any large current is taken from them. Thus, for example, a form of cell recently put upon the market had an electromotive force of 1·508 volts on open circuit, but after being short circuited through a wire of low resistance for fifteen minutes the electromotive force had fallen to ·433 volts. Polarization of a cell is mostly caused by alterations in the surfaces of the plates of the cell, and chiefly by the condensation of hydrogen on the inactive plate which sets up a reverse electromotive force, and so reduces the available electromotive force of the cell, at the same time reducing the available area of the plates, and thereby increasing the internal resistance of the cell.*

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* It is easy to demonstrate the reverse electromotive force, due to polarization by means of a water voltameter (§ 134). To do so let the current through such a voltameter be suddenly switched off, and the poles of the voltameter connected to a galvanometer; for a few seconds a current will be indicated by the galvanometer in such a direction as to shew that the pole of the voltameter from which the hydrogen was given off now acts as a zinc plate, *i.e.*, in the opposite direction to the current that was being driven through it before. The word "polarization" is frequently used in a loose way so as to include other causes which tend to weaken the current that a cell can give, as for example, the exhaustion of the exciting liquid, the forma-

To prevent polarization it is necessary to take some measures that will check or prevent the accumulation of hydrogen on the positive pole.

101. **Depolarizers.**—The constancy of batteries depends on the efficacy of the depolarizer used. Depolarizing methods can be conveniently grouped under three heads. (*a*) Mechanical methods. (*b*) Liquid depolarizers. (*c*) Solid depolarizers.

In *Smee's* battery the surface of the silver plate is roughened by being platinized, *i.e.*, covered with finely divided platinum, the effect of which is that the bubbles of hydrogen are able to form and escape more easily. In *Walker's* modification of this battery (see § 112, *Stöhrer's* battery) the rough surface of the carbon plate used plays the same part, but it probably acts chemically also by causing oxidation of the hydrogen in the same way that the carbon of charcoal filters causes the oxidation of the organic matter of impure water. Another mechanical method of hindering polarization is to keep the exciting fluid well stirred by forcing air through it or otherwise. None of these methods however are so efficacious as the use of chemical means, that is to say the use of some oxidizing agent in the cell whereby the hydrogen is consumed, instead of being deposited on the positive plate. The simplest method of doing this is to add to the exciting liquid some powerful agent that will oxidize the hydrogen as fast as it is liberated. This is the plan followed in the "bichromate" battery (§ 103) invented by *Poggendorf*. Another liquid depolarizer that is much used is strong nitric

tion of local currents owing to non-homogenity or bad amalgamation of the zinc, or the increase of internal resistance from changes in the exciting liquid, but strictly speaking the term should be limited to the changes at the surfaces of the plates of the cell.

acid, but as this attacks zinc violently it is necessary to separate it from the zinc plate by the use of a semi-permeable porous partition or porous pot, and the battery then becomes a two fluid battery. In fig. 36, the arrangement of a two fluid battery is shown; V is the porous pot containing one liquid and one plate, the other liquid and the other plate standing outside it.

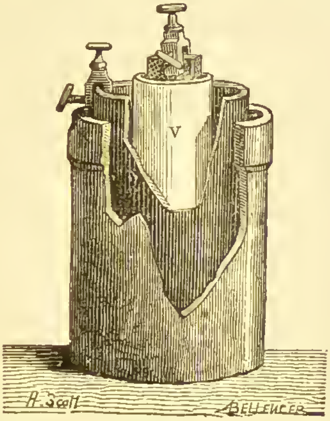

FIG. 36.—Two fluid cell

There are several valuable solid depolarizers in use, the one best known being peroxide of manganese, which is used in the Leclanché cell, and in several of the "dry" cells. Oxide of copper is also used. Fused chloride of silver is the depolarizer in a favourite battery for medical purposes, known as the chloride of silver cell, and the valuable qualities of peroxide of lead have had much attention drawn to them of late, through the study of its action in storage cells.

102. **Smee's battery.**—This battery is of interest, as representing the simplest advance on the copper zinc couple of Volta; it was invented in 1840. In its usual form it is made of two flat plates of zinc, separated from

one another above by a block of wood which supports a platinized silver plate between the zincs. To the zinc plates there is attached a large clamp and binding screw, which serves to hold the element together, another binding screw is attached to the silver plate, and this is the positive pole of the battery. The exciting liquid is dilute sulphuric acid 1 to 10. In spite of the roughened surface of the silver plate the battery soon polarizes, and its available electromotive force is not much more than ·5 volt.

103. **Bichromate battery.**—This is a favourite form of cell where large currents are required occasionally. Its constancy, however, is by no means perfect. Its plates are of zinc and carbon, and the exciting liquid consists of a solution of potassium bichromate and sulphuric acid. The sulphuric acid in the first instance sets free chromic acid, leaving potassium sulphate in solution. The chromic acid being a very powerful oxidizing agent, oxidizes the hydrogen produced by the action of the battery on the carbon plate, and is itself reduced to chromous oxide; this combines with a further quantity of sulphuric acid to form chromous sulphate, which remains in solution, giving the liquid a dark green colour. If such a battery is allowed to stand after much use crystals of potash chrome alum will be deposited, which are very hard and difficult to dissolve. Sodium bichromate has been strongly recommended instead of the potassium salt, as the sodium chrome alum is very much more soluble; the sodium salt also contains, weight for weight, more chromic acid than the potassium salt. A suitable formula, if sodium bichromate be used, is the following:—Dissolve 200 grammes of the salt in 1 litre of water and add 150 c.c. of strong sulphuric acid; when the battery begins to show signs

of being exhausted an additional 25 to 50 c.c. of acid per litre may be added. The chemical reactions occurring with this cell may be thus represented:—

$$K_2Cr_2O_7 + 2H_2SO_4 = 2KHSO_4 + 2CrO_3 + H_2O,$$

then $$2CrO_3 + 3H_2 = Cr_2O_3 + 3H_2O,$$

and $$Cr_2O_3 + 3H_2SO_4 = Cr_2\,3(SO_4) + 3H_2O.$$

The zincs of this battery must always be removed from solution immediately after use, and in fact should be well washed and frequently re-amalgamated, if the battery is to give the best effect. The reason for this will be easily seen when it is pointed out that *Dr. Weeren* has lately observed that pure zinc is one hundred and seventy-five times more soluble in acid containing a little chromic acid than in pure dilute acid. One form of bichromate battery is well known to medical men under the name of *Stöhrer's* battery, but it is hardly to be recommended as it requires much attention and

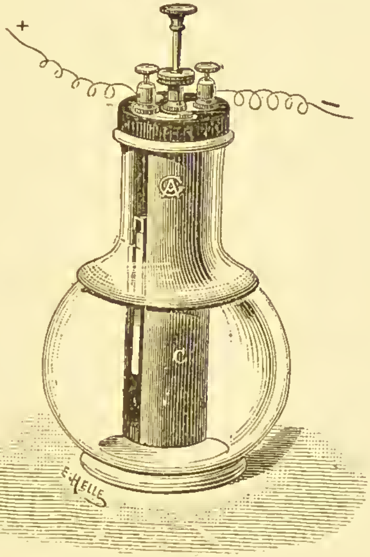

FIG. 37.—Bichromate battery.

cleaning, and is by no means economical in use, it will be more fully described in § 112. The outward form of the bichromate battery varies very much. A very familiar shape is that of a wide mouthed and long necked bottle (fig. 37). The plates are suspended from a vulcanite lid carrying binding screws, and the zinc plate can be drawn up out of the liquid into the neck of the bottle when the battery is not in use.

104. **Daniell's battery.**—The oldest and most constant form of two fluid battery is that known as Daniell's cell. So constant is this cell that it has been proposed and frequently used as a standard of electromotive force. For rough purposes we may take the electromotive force of a Daniell's cell at one volt. A Daniell's cell consists of a copper plate placed in a solution of sulphate of copper, which is kept saturated by leaving a few crystals of copper sulphate on a shelf near the top of the liquid; separated by a porous partition is a zinc plate in solution of sulphate of zinc slightly acidified with sulphuric acid. Frequently the copper plate is made also to serve as the containing vessel. The porous partition while it prevents the mixing of the two solutions, offers but little resistance to the electrolytic passage of the current. The reactions then are as follows:—Zinc is dissolved at the zinc plate and hydrogen would be set free at the division between the two liquids but for the presence of the copper sulphate solution which being itself an electrolyte is decomposed into sulphuric acid, which passes inwards from the porous partition, and copper which is deposited at the positive pole. Since this latter is already of copper there is no tendency to polarization here at all, and any falling off in the electromotive force of the cell is due to bad amalgamation or some other fault at the zinc plate.

Daniell's batteries are frequently arranged as "gravitation batteries," the porous division being abolished and the lighter liquid dilute acid with the zinc plate being above the heavier sulphate of copper solution. *Sir W. Thomson* fills them with sawdust, thus avoiding any danger from upsetting the battery. The drawback to the use of a Daniell's battery is that no matter how perfect the porous partition may be some of the copper salt will diffuse sooner or later through to the zinc and copper will be deposited on its surface, giving rise to local action and waste.

105. **Groves' and Bunsen's batteries.**—These have for their depolarizer strong nitric acid. In the former the positive pole is a platinum plate, in the latter a plate or rod of hard gas carbon. In both batteries the positive pole is contained in a porous pot filled with strong nitric acid and this is surrounded by the zinc plate contained in a vessel filled with dilute sulphuric acid (fig. 36). The action of the battery may be looked upon thus:—At the porous partition the electrolysis is taken up from the dilute sulphuric acid by the nitric acid and the hydrogen that would be given off at the platinum or carbon pole is oxidized by the nitric acid to water, the acid being reduced and decomposed with production of nitric oxide. This is partly dissolved in the rest of the nitric acid giving it a green colour and part escapes into the air where it combines with oxygen to form the corrosive red fumes of the higher oxides of nitrogen. These fumes and the general uncleanliness and corrosiveness of nitric acid form the greatest objection to the use of this battery.* If it can

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* It will be found that after a little use the platinum plates used in Groves' battery have become very brittle. They can be restored to their former soft state by heating them red hot in a Bunsen flame.

be set up in a draught cupboard or out of doors it is a good battery for lighting or cautery heating purposes.

106. **The Leclanché battery.**—The cell most universally used for medical work is the Leclanché battery, the exciting liquid in which is a saturated solution of ammonium chloride (sal ammoniac) fig. 38. The negative pole is a zinc rod and the positive pole a carbon plate or rod. This is surrounded by the depolarizer, manganese dioxide, which is able slowly to oxidize any hydrogen evolved by the action of the cell. In the older forms of Leclanché cell the carbon pole was packed tightly in a porous pot with fragments of carbon and granular manganese dioxide. The more modern form of cell has no porous pot, and thus its internal resistance is reduced, but the carbon has attached to it under a pressure of about 300 atmospheres a conglomerate formed of 40 parts manganese dioxide, 52 carbon, 5 of

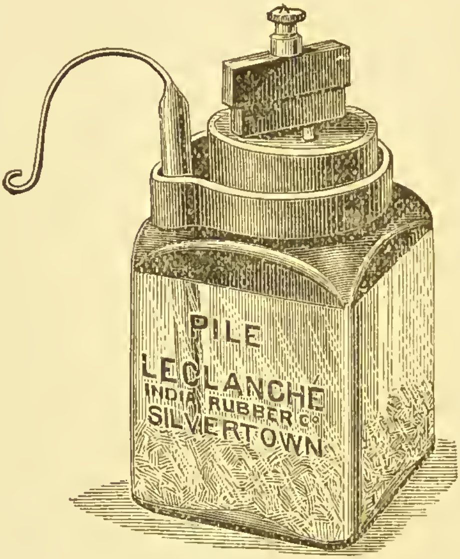

Fig. 38.—Leclanché cell.

shellac and 3 of potassium bisulphate. This form is called the agglomerate type. The addition of a little chlorate of potash to the exciting solution has been recommended in the proportion of one part chlorate to three of sal ammoniac. It is possible that this addition may help to make the depolarizing action more complete.

The chemistry of the cell cannot be expressed in any simple manner. When the circuit is open there should be absolutely no action between the solution and the zinc (local action) and this makes the cell a very economical one, but when the circuit is closed the zinc is dissolved, forming a double chloride of ammonium and zinc, and an oxychloride of zinc while ammonia and hydrogen are evolved at the carbon pole. If only a small current is taken from such a cell the manganese dioxide does its work and the cell is fairly constant, but if much current is used the oxidizing action of the manganese dioxide is unable to keep pace with the evolution of hydrogen and the cell is rapidly polarized, though it recovers completely if left for some hours on open circuit. The electromotive force of a Leclanché cell is about 1·6 volts. The advantages of the battery are that it possesses great power of recovery, has no appreciable local action and may consequently be left for months at a time without attention, and has a fairly high electromotive force. Against these we must set its high internal resistance and the fact that its electromotive force runs down very rapidly when it is called on to produce a current of any magnitude.

None of the cells in which dilute acid is used for the exciting liquid can be left to themselves in the way that Leclanché batteries can for in all of them the local action would soon destroy the zinc if it were not removed from the acid as soon as the battery has been used, and on that account alone they are not very suitable for medical purposes, since they require too much attention; means have been devised for facilitating the removal of the plates from the acid when the battery has been done with, but there still remains the difficulty of dealing with the liquids, especially during the transport of the battery from one place to another. Medical batteries must allow of being carried to patients' houses when necessary, and the ordinary open cells with acid liquids in them are most awkward; the liquid is easily upset and corrodes whatever it touches, consequently medical men are ready to make considerable sacrifices in other directions for the sake of a closed cell, in which the trouble of attending to the zincs can be got rid of, and in which there is no risk of upsetting acids. Accordingly, except for very special purposes, the Leclanché cell is almost universally employed, for in it the zinc can be left always in position without waste from local action, and the cell can be closed in with pitch or cement, to prevent any escape of the exciting fluids from within; these conveniences are purchased at the cost of a high internal resistance and of a tendency to polarization, but for most medical work these objections are not very serious, because the huge resistance of the human body reduces by comparison the internal resistance of the battery to an almost negligeable quantity, and because the amount of current required in most cases is only a few thousandths of an ampère. (5 to 50 milliampères). Even when the portability of the battery is not important the Leclanché element is still preferred, for once installed in a cellar or a cupboard, it can be left alone without attention for months or even years, and by the use of large cells instead of small ones, the internal resistance can be somewhat reduced, while the capacity of the cell for doing work can be increased. The Leclanché cell then is the one most commonly used for medical purposes, and its management, mode of action, defects and good qualities should all be thoroughly mastered once for all by those who intend to work at the subject of medical electricity.

Numberless modifications of this cell have been put upon the market at different times, but these have differed from the original type mainly in such details of construction as shape of cell, omission of porous pot, and shape of plates. We shall further consider one of the modifications in treating of "dry" batteries (§ 109).

To preserve Leclanché cells in good order they must receive a little attention from time to time about once in six months or so. The larger sizes in glass jars can be easily inspected, and the condition of the zincs and the level of the liquid ascertained.

If the zincs are blackened they should be scraped and amalgamated, and the liquid can be renewed by adding water to replace what has been lost by evaporation. The cells must not be filled to more than two-thirds of their capacity. If the amount of work done by the battery has been large the old solution had better be withdrawn by means of a syringe or a syphon, and fresh solution put into its place. The proportion of six ounces of sal ammoniac to a pint of water makes a solution of proper strength. The upper inch of the glass cells ought to be brushed over with vaseline or hot paraffin wax to prevent *creeping* of the salts. This is the formation of crusts of the sal ammoniac around the top of the cell, it is harmful because they may connect together two neighbouring cells, so closing a circuit, and wasting the battery.

When large crystals form in masses at the bottom of the cell and round the zincs it is time to take down the battery and set it up afresh. These crystals are a double chloride of zinc and ammonium, and are insoluble in water, but they can be dissolved in dilute hydrochloric acid, and this is the simplest way of getting rid of them. When they have formed in the outer vessel, they have probably formed in the porous pot as well, and their presence there is not desirable because they increase the internal resistance of the cell, and block up the interstices of the carbon and manganese dioxide. When the battery is being renewed the liquid inside the porous pot should be poured off through the small holes at the top, and dilute hydrochloric acid (1 to 20) poured in and left for twenty-four hours, and after that the porous pot must be soaked for another day or two in water. This proceeding will much improve the battery. If there is reason to think that the cells are worn out they may be recharged with manganese dioxide and broken carbon, or better still they can be replaced by new ones. The management of the small Leclanché cells used in portable batteries is much more difficult, because it is impossible to see their condition; one can do little beyond emptying out the liquid with a fine syringe and putting in fresh sal ammoniac solution in the same way from time to time, and to do even so much as this is a tiresome operation, because of the tangle of wire connections which lies over the tops of the cells in a portable battery.

107. **Chloride of silver cell.**—The chloride of silver battery was invented in 1868 by *Warren de la Rue* and *Hugo Müller*, and modified and improved by *Skrivanoff* in 1883. It possesses qualities which make it very suitable for medical work but it is a somewhat ex-

pensive cell to buy. The poles of the cell are zinc and silver and consequently its mean electromotive force is about one volt. The silver positive pole consists of a wire of silver round which is cast a thick coating of silver chloride, this is enclosed in a cylinder of parchment paper that there should be no risk of short circuiting from contacts inside the cell. The plates can therefore be brought very near to each other and the internal resistance of the cell minimised. The exciting liquid used by *De la Rue* was a strong solution of sal ammoniac similar to that used in the Leclanché battery. *Skrivanoff* used for the exciting liquid a solution of caustic potash containing seventy-five parts caustic potash to an hundred of water, this increased the electromotive force to about 1·5 volts and generally improved the action of the battery. *Mr. Schall* of Wigmore Street has taken considerable pains to improve this form of battery, and his cells are certainly very neat and convenient; the chief drawback to their use is the high first cost of the chloride of silver, but it is claimed that the reduced metallic silver which is formed in the cells is not wasted and that it can be reconverted into chloride and used over and over again so that the working cost of the cells ought not to be very great. The internal resistance of a chloride of silver cell is low

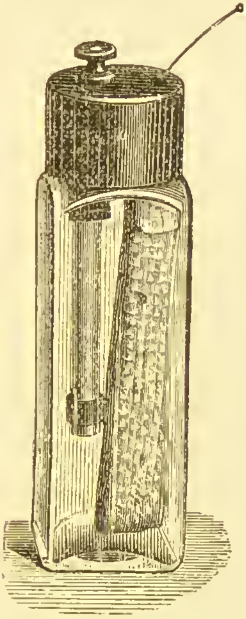

FIG. 39.—Chloride of silver cell.

after the action is once well started, and it is not easily polarized so it is possible to take a large current from these cells if required (fig. 39).

It is stated that a cell of *Skrivanoff* form weighing one hundred grammes with an electromotive force of about 1·5 volts will give a current of one ampère for one hour. If this is true the chloride of silver cell must apart from its cost be one of the best of all primary batteries. If it were attempted to take such a current from a Leclanché cell even of large size it would polarize almost at once. Besides, its internal resistance would probably be too high for it to be possible to take such a current from it.

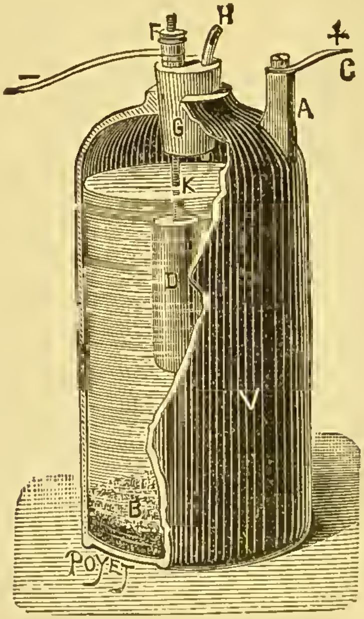

Fig. 40.—Lalande and Chaperon's oxide of copper cell.

108. **Oxide of copper battery.**—A cheap and efficient form of battery in which the depolarizing action of cupric oxide is made use of, has been introduced by M.M. Lalande and Chaperon. The most typical form

of this cell consists of a cast iron vessel shaped like a short truncated cone, this makes the positive pole of the battery, and contains at the bottom a layer of oxide of copper and holds the exciting liquid, a solution of caustic soda. The vessel is provided with a lid of insulating material or an indiarubber stopper carrying the zinc, and must be hermetically sealed, to protect the caustic soda solution which would otherwise absorb carbon dioxide from the air (fig. 40).

109. **Dry batteries.**—Of late there have been several so-called dry batteries put forward and these are in many ways exceedingly convenient. These are sealed cells usually of the Leclanché type. They will work in any position and require no special attention whatever, at the same time it must be remembered that all sealed forms of cell have a capacity for work strictly limited by the original charge of chemicals, and cannot be restored to action when run down by the addition of fresh exciting liquid. The oldest form is called *Gassner's* dry cell. In this the zinc plate is shaped like a canister and forms the containing vessel of the cell, it is lined (jacketted) with a layer of oxide of zinc and inside this is the carbon and manganese dioxide. The whole is mixed with sal ammoniac and other salts and packed moist. Cells of similar type can be obtained from the Electric Power Storage Company, from the Electric Supply Company, and from *Messrs Siemens Bros.*

The dry battery lately brought out by *Messrs Siemens, Bros. and Co.* under the name of "Hellesen's patent dry cell" seems to work very satisfactorily (fig. 41). Like the other dry cells it appears to be a modified Leclanché battery as the poles consist of amalgamated zinc and carbon and the exciting salt is sal ammoniac, while the depolariser is manganese dioxide. A cell measuring three inches by three inches by six and a half inches weighed about three pounds and a quarter, had an electromotive force of 1·4 volts and a resistance of about ·07 ohms. The electromotive force scarcely changed with temperature. After being short circuited through an external resistance of three ohms for thirty-six hours the internal resistance had risen to ·17 ohms. After one hour of such short circuiting the electromotive force had fallen to 1 volt and after 24 hours to ·34 volt but after 24 hours rest it had recovered to 1·08 volts. This, considering the severity of the treatment, is a most satisfactory result. *Mr. Shelford Bidwell* has made some tests of these cells and has found them capable of giving a current for a few seconds of over twelve ampères. He was able to light a small lamp of two and a half candle power with six of them in series and found that the current fell off in two minutes by about 7 per cent.; when six large bichromate cells were used the current decreased in the same time by more than 20 per cent. From this it appears that while such cells would

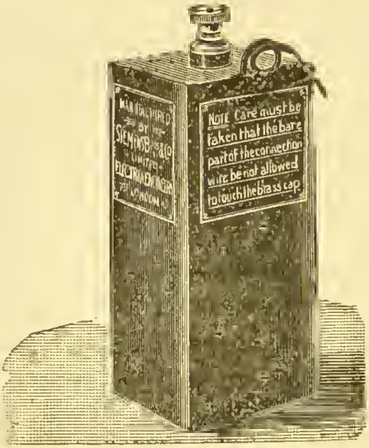
Manufactured by Siemens Bros & Co Limited Electrical Engineers London
Note Care must be taken that the bare part of the connection wire be not allowed to touch the brass cap.

FIG. 41.—Hellesen's patent dry cell.

be perfectly competent to do the work that the medical man ordinarily requires of a Leclanché, several of them might at a push be successfully used to heat a cautery or light a glow lamp.

Mr. Coxeter is at present preparing a new form of dry cell on the principle of Daniell's battery, replacing the fluid by a jelly containing the depolarizing compounds. The electromotive force is a little less than a volt but no tests of sufficient length have yet been made as to its durability. From some preliminary tests it would appear to possess good qualities.

110. **The sulphate of mercury battery.**—A battery that has been largely used for medical purposes, especially in the portable faradic coils sold by *M. Gaiffe* of Paris, consists of plates of zinc and carbon in solution of sulphate of mercury. In some ways this is a convenient form of battery but it is hardly to be recommended as it is very dirty. In the form mentioned above two cells are generally supplied. There are trays of gas carbon on which is placed a small quantity of the commercial sulphate of mercury, probably consisting of a mixture of mercuric and mercurous salts, and a little water; the zinc plates are then laid on this and are kept from contact with the carbon by three vulcanite studs. The electromotive force is about 1·45 volts. There are several forms of this battery, one has been much advertised under the name of the Schanschieff battery.

111. **Latimer Clark's standard cell.**—With the sulphate of mercury battery, this cell, which has been thoroughly investigated by *Lord Rayleigh* as a standard of electromotive force, must be mentioned. It consists of a short glass tube through the bottom of which a platinum wire is sealed, a little pure redistilled mercury is poured in and on this there is a paste of protosulphate

of mercury. Over this is a saturated solution of pure sulphate of zinc in which is suspended a rod of pure zinc. The electromotive force of such a cell is 1·434 volts at 15° C. and it falls about ·001 volt for every increase of 1° C. Such cells must never be short circuited and are only used for comparison of electromotive forces. A form of this cell put up for testing purposes with a thermometer is sold by instrument makers.

112. **Stöhrer's battery,** which is largely sold to medical men, is a compact though clumsy form of bichromate battery. The elements, zinc and carbon, are arranged in a double row on a wooden bar, so that a double row of glass or earthenware cells containing the exciting fluid can be raised up to them in such a manner that the correct pairs of plates dip into each cell (see fig. 42).

The battery may be made up to contain 20, 30, 40, or even 60 cells, these form a double row in a strong oak box, and a beam of wood with a deep channel cut in it extends from end to end of the box in the middle line; the pairs of plates are all suspended from this beam by stout brass rods, which convey the current from the cells to the travelling collector. Each row of cells has its plates coupled up in series by brass connexions, and is not connected with the other row except at one end where the zinc of the end cell in one row is connected by a wire with the carbon of the corresponding cell of the other row. Thus the cells in the two rows face in opposite directions, and the plates form an unbroken alternate series from end to end of the battery.

Cells can be taken up into circuit by twos, starting from the end of the box, where the cross connexion occurs, and the beam carries numbers, 2, 4, 6, &c., by which the collector can be set to include the indicated number of cells. So when the collector is set at six, there are six cells in series in circuit, three being taken from each of the rows of cells, and the number of cells in circuit can be altered by steps of two at a time, so that any even number, from two upwards, can be included.

The collector which slides in the groove of the beam carries two flat brass springs which make connection with the brass rods from which the pairs of plates hang.

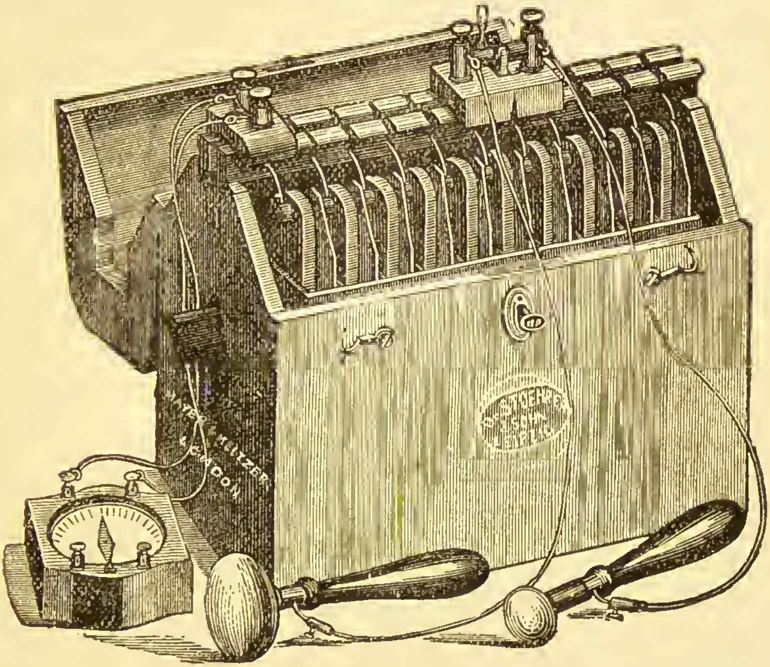

FIG. 42.—Stöhrer's battery.

From the springs the current is led through a commutator (§ 126) to a pair of binding screws, and from these the wires may be led to the place where the current is required. It may be noticed that *Stöhrer's* battery was originally designed for use with dilute acid only, as in *Walker's* modification of *Smee's* cell, but the addition of the chromic acid depolarizer obviously improves its action.

The battery is not portable owing to the quantity of corrosive liquid in the cells, and it is very troublesome and difficult to keep it clean, and its zinc plates amalgamated. It is therefore not to be recommended.

113. **Accumulators or secondary batteries.**—Many different forms of cautery batteries are sold by instrument makers. These are usually arrangements of the bichromate cell, so set up as to diminish its internal resistance. Some have single plates of large size, and others have in each cell many plates of zinc and carbon arranged alternately in close proximity to each other. The trouble and expense of charging them and the corrosive nature of the exciting fluid are grave objections to their use, and it is no longer necessary for the surgeon to be dependent on them, for their place is well filled by *storage cells* or *accumulators*, which can be easily bought or hired, at any rate in our large towns. A so-called *secondary battery* in reality only differs from a primary battery of any of the types that we have been describing, in that when it is run down and exhausted it may be renewed by driving an electric current into it and thus setting up an electrolysis that brings the chemicals used back to their former state, while in the *primary batteries* it is necessary to renew the whole of the chemicals. It is therefore a misnomer to speak of the "storage of electricity." There is no more actual storage of electricity in one of these batteries than in a primary battery. Either may be looked upon as a store of energy, and in both the energy stored is energy of chemical action. Secondary batteries are generally of one of two types, in both of which the plates are of lead. The older cell of the *Planté* and *Faure* type had porous

lead plates, placed in dilute sulphuric acid as the electrolyte, these cells then require "forming," that is, they are connected up in series and a current passed through them for a certain time, and they are then allowed to discharge themselves through a resistance, they are then charged in the opposite direction and allowed to discharge again, and this process is repeated several times. The object of this "forming" process is to increase their capacity. These cells are costly and heavy and the plates become very rotten, but they possess the advantage that they may be fully discharged without damage, while it will be seen that the other type of cell is seriously impaired if allowed to fully discharge itself.

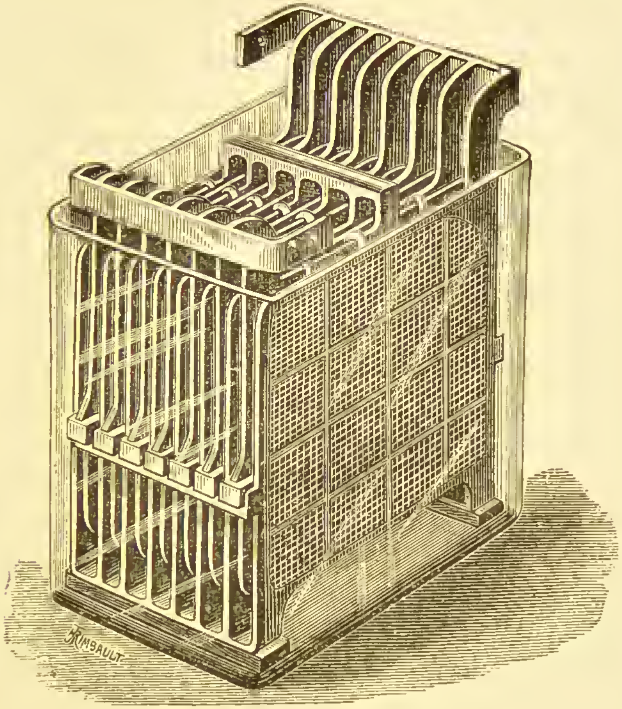

FIG. 43.—Accumulator in glass vessel, showing arrangement of plates.

The other type of cell is that usually supplied by the large electric lighting companies and it is often known as the "E. P. S." (Electrical Power Storage) cell; the plates are perforated grids of lead, or, in the latest cells, an alloy of lead which is stronger than the pure metal.

The holes, which are filled with a composition, are slightly tapered from the middle of the thickness of the grid, and this undercutting prevents the paste from falling out so easily as it would otherwise do. The grids which are intended to be positive plates have in the latest forms rather larger holes than those which are to be negative, and it has been proposed to make them entirely of peroxide of lead, doing away with the lead grid altogether. The holes in the positive plates are filled with a paste made of red lead or puce coloured oxide (peroxide) of lead and dilute sulphuric acid, which sets fairly hard in them. Those in the negative plate are filled with a paste of litharge and sulphuric acid. The plates, formed into "sections" of positive and negative plates arranged alternately, are placed in the cells, and these are filled up with dilute sulphuric acid of sp. gr. 1·170 and they are ready for the first process of charging. This is called "forming" the cells, and consists in charging them for a very long period, say about thirty hours. The sp. gr. of the acid rises in this time to about 1·210 and when the charging is complete the liquid has a milky appearance owing to the bubbles of electrolytic gas given off from the plates from the decomposition of the water in the electrolyte. If the positive plates have been pasted with peroxide of lead the cells will not require so long a forming. When a cell has just been charged it will be found to have an electromotive force of nearly 2·5 volts, but this quickly falls to about 2·2 volts, even if the cell is left on open circuit, and after a short discharge, the cell only gives about 2 volts. When the cells are discharging the electromotive force is maintained till about 75 per cent. of the ampère hours that the cell will give has been done, and then the electromotive force begins to fall again. However, as the batteries must never be discharged beyond this point this is no drawback to their use, but rather an advantage, as by the use of a voltmeter (§ 131) such as is supplied for the purpose by the E. P. S. company and others, it is always possible to test each cell of the battery and discover when it requires recharging. It may be taken as a general rule that as soon as the electromotive force of a cell falls below 2 volts or 1·9 at the lowest that cell should at once be recharged. It would be out of place here to enter into the reasons for this. Suffice it to say that if it is not attended to higher sulphates of lead are liable to form in the cell which increase its internal resistance and decrease its storage capacity and the grids are liable to buckle and lose their paste.

It is not easy to give much idea of the storage capacity of these cells, but a well designed one should be capable of giving about 5 to 7 ampère hours per pound of lead.

The internal resistance of a storage cell is almost infinitesimal when it is in good order, and may generally be neglected in calculations concerning them unless a very large number are coupled up in series, since the current that may be taken out of the cell is limited by other considerations. It is found that the density of current (§ 68) in a storage cell should not exceed ·065 ampère per sq. cm. of positive plate. If this limit is exceeded, the paste is liable to leave the plates. It is, however, sufficient for all practical purposes, for the largest size of E. P. S. cell can give a current of 60 ampères. It is not necessary to go thoroughly into all the troubles that may arise if accumulators are misused, it is sufficient merely to give a warning as to the modes of treatment that will certainly damage the cells. First and foremost among them is the practice of flashing the cells to see if they are in working order, viz., taking a spark from them by clamping a thick wire to, say the negative pole, and touching the positive pole with the other end of the wire. This treatment loosens the paste and tends to set up deleterious sulphating in the cells. They should always be tested with a proper voltmeter or with a glow lamp of the right size. Next, when a large current is to be taken from the cells, *e.g.*, one approaching the maximum permissible current, the cells should not be suddenly turned on but " eased down " through a resistance. That is to say, if a large cautery is to be heated, a resistance should be included in the circuit which can be decreased till the required current is obtained. The cells must never be allowed to fully discharge themselves, they should be tested from time to time, and as soon as the electromotive force of a cell sinks to 1·9 volts that cell must be disconnected and recharged. Further information will be found in *Sir D. Salomons*' book, " Management of Accumulators."

114. The internal resistance of a cell, though a most important factor in calculations concerning the best arrangement of batteries for any particular purpose, is so indefinite a quantity, and varies so much with the size, nature, and plan of construction of the cell, that it is impossible to say anything very definite about it, much less to tabulate it for the different forms of batteries. An internal resistance which at all nearly approaches an ohm makes a battery useless for cautery heating or

electric light. A Smee's battery in which the plates are one centimetre apart and ten by five centimetres in area

TABLE OF BATTERIES.

NAME.	ACTIVE PLATE	EXCITANT.	DEPOLARIZER.	PASSIVE PLATE.	APPROXIMATE ELECTROMOTIVE FORCE VOLTS
1. Smee	Zinc	Dilute sulphuric acid, 1-8	None	Platinized silver	·8
2. Bichromate	"	" 1-8	Chromic acid	Carbon	1·9
3. Sulphate of Mercury	"	" 1-20	Acid sulphate of mercury	"	1·5
4. Latimer Clark's standard cell	"	Zinc sulphate	Mercurous sulphate	Mercury	1·438 legal volts. 1·434 true volts.
5. Daniell	"	Zinc sulphate or dilute sulphuric acid, 1-12	Copper sulphate in porous pot	Copper	1·079
6 Grove	"	Dilute sulphuric acid	Strong nitric acid in porous pot	Platinum	1 9
7. Bunsen	"	"		Carbon	1·9
8. Lalande and Chaperon	"	Sodium or potassium hydrate 40 per cent.	Cupric oxide	Iron or copper	·7
9. De la Rue	" *	Ammonium chloride saturated solution	Silver chloride	Silver	1
10. Skrivanoff	" *	Sodium or potassium hydrate 75 per cent.	"	"	1·5
11. Leclanché	" *	Ammonium chloride saturated solution	Manganese dioxide with or without porous pot	Carbon	1·48
12. Coxeter	"	Zinc sulphate	Cupric salt	Copper	? 1
13 Gassner	" *	Ammonium chloride	Manganese dioxide	Carbon	1·5
14. Hellesen	" *	"	"	"	1·5
15. Secondary battery	Lead	Dilute sulphuric acid, sp. gr. 1·170	Lead peroxide	Lead	2

would have a resistance of about ·05 ohm as calculated from the specific resistance of the acid used, but owing to real rise of internal resistance and fall of electro-

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* In cells marked thus the zinc is not always amalgamated.

motive force due to polarization the apparent internal resistance when in use is much greater. The resistance of the bichromate cell depends upon its size and make, generally speaking in the types manufactured for cautery heating and for lighting it is made as low as possible and is very small. The resistance of Daniell's cell depends on its size and the thickness of the porous pot used and varies from about ·3 to 3 ohms. A quart Grove cell has a resistance of about ·15 ohm. Lalande and Chaperon's battery is made in several different shapes, in the most typical form the internal resistance may be brought as low as ·03 ohm. Although initially the resistance of a chloride of silver battery is very high owing to the bad conductivity of the silver salt, as soon as a small quantity of this has been reduced to metal the resistance falls and may be very low indeed. That of a Leclanché cell varies from about ·5 in the largest sizes to two, three, or five ohms in the smallest ones. The internal resistance of Gassner's dry cell is said to vary very irregularly in use, that of the Hellesen battery is given by the makers as from ·05 to ·7 ohm according to size. The secondary batteries all have a very low internal resistance indeed, according to the number and size of the plates. Thus it will be seen that it is advisable for .every owner of a battery to determine its internal resistance for himself.

115. **On the choice of a battery.**—Medical men are frequently asking for advice as to the choice of a battery. They would like to have one which would answer all the purposes for which it could possibly be required, which would be portable and cheap, and would not require constant or frequent attention. At present it is not possible to combine all these properties in one battery. It is probable that two separate outfits at

least will be required, and if many patients are to be treated perhaps more. Where possible it is far more convenient to bring the patient to the battery than to carry about a portable battery to the patients, but

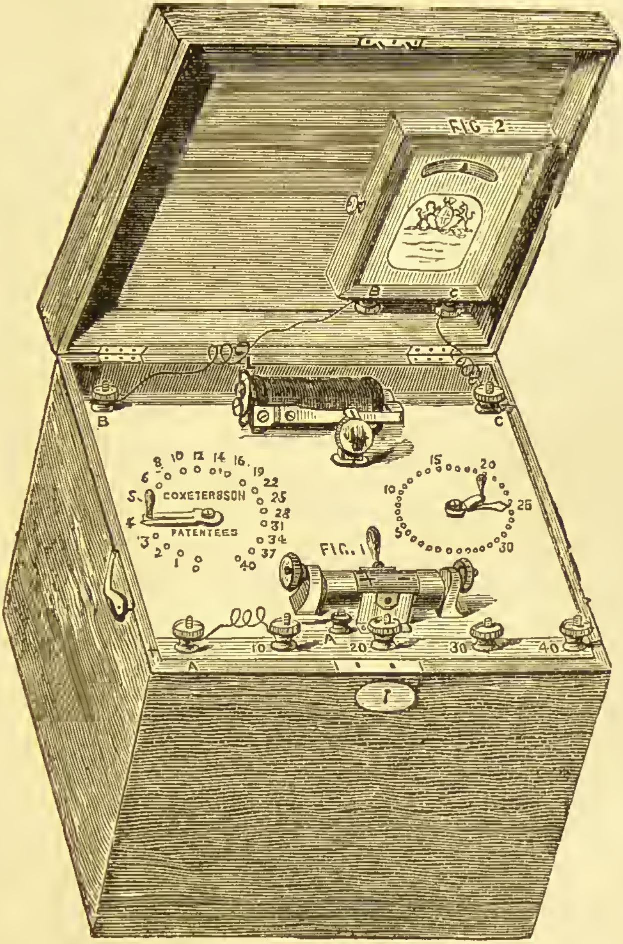

FIG. 44.—Coxeter's combined battery.

where this is not possible, portability must be made the first object. Small and portable batteries are sold by the various instrument makers consisting of from 30 to

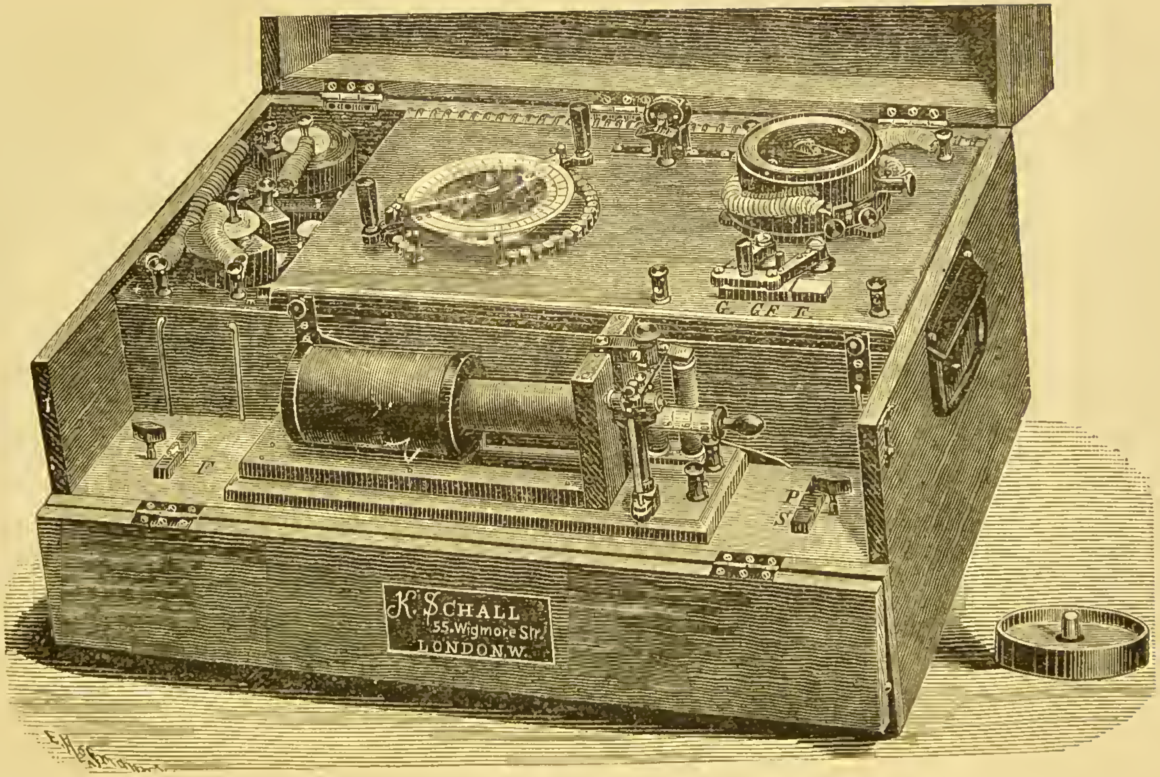

FIG. 45 —Schall's combined battery.

60 cells arranged in a case and fitted with commutator, current collector, faradic coil and galvanometer. These are quite suitable for testing the reactions of nerve and muscle, for galvanisation, or the electrolysis of small nævi. The cells used are most commonly of the Leclanché type, or may be of the type of so called "dry" cells that are now on the market. Owing to their small size they have necessarily a high internal resistance and if any considerable current is required to be taken from them, the plates quickly prove unequal to the task and become polarized or even permanently damaged thereby. For those uses to which they are most adapted, their high internal resistance does not matter much, since it is small in comparison with the resistance of the human body which amounts to from one thousand to three thousand ohms, but their tendency to polarize and their small capacity is far more serious as it compels their frequent renewal. *Mr. Coxeter* and *Mr. Schall* have both given much attention to this form of battery and their catalogues may be consulted by those wishing to purchase anything of the sort. If electro-diagnosis and faradic currents only are required fewer cells are needed and there are many convenient portable forms in the market. Several particularly compact ones are sold by *M. Gaiffe* of Paris. These, however, are mostly fitted with the somewha imperfect sulphate of mercury element.

The electrolysis of nævi is an operation which taxes small Leclanché cells to the utmost, requiring as it does a current of from 60 to 200 milliampères, and if a battery of these cells be much used for this operation, then frequent renewals will become necessary, and make the small battery more expensive than a large one. As a general rule it is wasteful to use small portable cells unless the circumstances of the case make it difficult to use large ones.

When portability is not a *sine quâ non* the difficulties of the choice are greatly lessened, for sixty large cells suitably arranged (§ 69) will give enough current for all purposes. The Hellesen type of dry cell seems to be a very promising one, since its internal resistance is low and its tendency to polarize is small; it may even at a pinch be possible to heat a cautery with a sufficient number of these arranged in parallel; and with five or six arranged in series so as to give sufficient electromotive force, a small lamp for a cystoscope or other instrument can certainly be lighted. As a rule for a fixed installation for galvanic and faradic work sixty large Leclanché cells are fitted up, and these are convenient as they require little attention and remain in good order for long periods. They will also furnish sufficient current for electrolysis of nævi, &c., but hardly for an electric bath. For this latter a bichromate battery of Dr. Stöhrer's type is generally used but it would appear that the Hellesen battery is as suitable for the work and far more convenient. A battery for dealing with low external resistances such as cauteries and lamps must be of an entirely different type. Bichromate batteries have been and still are largely used for these purposes in spite of their many disadvantages. But they are always so troublesome and wasteful and the violently caustic liquid that they contain makes them so inconvenient to carry that they cannot be recommended. The qualities required, so far as the electrical part of the work is concerned, are low internal resistance and absence of polarization, while a high electromotive force is not necessary. Of course absence of polarization may be taken to imply the ability to supply a large current. Except for their weight there can be no better battery than a few cells of the secondary type, but unfortunately the quantity of lead that they contain makes them exceedingly heavy. These cells have an intrinsically high electromotive force, and are not difficult to manage if the precautions indicated in § 113 are attended to. A battery of four or six small storage cells in a case can be closed so that no acid can splash out, and with a switch board so arranged that they can be connected in parallel or series as required, with an open wire resistance for regulation, and an ammeter, can be made into a compact and convenient if somewhat heavy instrument. With such a battery arranged with the cells in parallel almost any low resistance cautery could be heated, and arranged in series, there would be sufficient electromotive force to light any ordinary surgical lamp.

It is possible that some of the so-called dry cells of a larger size that are now being brought out may be capable of doing the work required, but at present accumulators seem to be the most convenient form of battery the surgeon can use for low resistance work, though they are of course useless for high resistance work as so large a number would be required.

116. **Care of batteries.**—It would seem to be advisable before leaving the subject of the battery to say a little as to the care of a battery. In the most modern types such as the chloride of silver, Hellesen's, Gassner's and other closed cells, no attention need be given so long as the electromotive force remains at its normal value, except that the cells must not be left short circuited and should be kept clean, while care must be taken never to draw from them a larger current than they are intended to give. Of course when the electromotive force shows any considerable signs of

falling off it is time to have the cells renewed. Enough has probably been said in § 113 as to the care of storage cells. Leclanché batteries also require but little attention, beyond occasionally filling them up to the proper level with water to make up for loss by evaporation. Should the exciting liquid show a tendency to creep up the sides of the cells this should be stopped. The usual method is to coat the upper part of the cells with paraffin wax for a depth of an inch or so inside and out.

The batteries that really need attention are those in which the exciting liquid is dilute acid, so that what is here said on the subject will apply to the following types, Smee's, Grove's, Bunsen's, Daniell's and bichromate cells and also to a certain extent to sulphate of mercury batteries. The first and most important point to be considered in all these cases is that all contacts shall be bright and clean so that there is good metallic connection wherever it is wanted, and too much trouble cannot be expended on this. An old file and a piece of coarse emery cloth well applied will do wonders here. Then the zincs must be well amalgamated. They should be scraped and brushed to show a moderately clean surface and wetted with dilute acid, and then mercury to which a little solution of nitrate of mercury or a few drops of nitric acid have been added should be well rubbed in with a piece of stick; a piece of firewood somewhat rotten and shredded by the action of the acid does very well. The surface of the zinc when properly amalgamated appears to be wetted by the mercury at every point. If this is properly carried out there will be little loss from local action in the battery. In filling Bunsen's and Grove's batteries care should be taken that the nitric acid does not spill into the compartments for the zinc, and after use the liquids may be stored separately for future use until exhausted. These batteries should always be dismounted when done with and carefully cleaned before storing away; a little trouble spent here will save a great deal when the battery is required again. Bichromate cells want constant attention. It is not easy to tell when the exciting liquid is exhausted and as it is very opaque it is also difficult to tell if there are many crystals formed in it. If sodium bichromate be used instead of the potassium salt the tendency to crystallize is much reduced since the sodium chrome alum is far more soluble than the corresponding potassium salt. In any case the carbon plates should be occasionally soaked in warm water and sometimes brushed with a hard or wire brush. On no account should the zincs be left in the chromic solution when not in use as it attacks even pure zinc with some facility.

Sulphate of mercury batteries are somewhat messy to use and should always be well cleaned. It is well to remember too that mercury contaminated with acid salts of mercury amalgamates most metals more easily than pure mercury. It is perhaps hardly necessary to observe that all gold ornaments or coins must be carefully kept from contact with mercury.

The utmost vigilance must be perpetually exercised to guard against accidental or intentional short circuiting of any battery. No battery will stand short circuiting for many minutes, and the batteries most used in medical practice are particularly sensitive to it, their life is shortened and excessive polarization takes place from which in all probability they never completely recover. Short circuiting may easily occur if bare electrodes are carelessly thrown down after use.

When a battery has been dismounted and put together again, especially if it has many complex connexions there is a danger that the positive pole may have been accidentally connected to the binding screw marked negative and *vice versâ*. This is sometimes the case even when the repairs have been done by an instrument maker. This is an important point because confusion of the poles may lead to serious mistakes and even to injury to the patient. All risk can be done away with by the use of some method of testing the polarity of the electrodes. Pole testers are made by electrical instrument makers and a neat form is sold by *Messrs. Woodhouse and Rawson*. It is very easy, however, to improvise such a thing. A piece of wet litmus paper on a sheet of glass, will show by changes in colour at the electrodes which is the positive and which the negative pole. The ends of the circuit must be rested on the paper for a few minutes, electrolysis will take place and the litmus will be reddened by the acid liberated at the anode or positive pole, and will turn blue at the kathode or negative pole. Many other reagents have been proposed, a solution of phenol-phthalein in dilute alcohol contained in a vessel, into which the poles can be dipped answers very well, giving a purple red colour at the kathode or negative pole.

117. **Use of electric lighting currents.**—It is hardly likely that the dynamo will be much used at present by medical men as a generator of the electric current, no account therefore need be given of it here, we need only refer the student to works on the subject of which a few were indicated in § 77. But the distribution of current for lighting purposes is becoming more and more universal daily, and it is probable that in the course of the next few years there will be few large towns in which it will be impracticable for medical men

to have current brought into their houses from the town mains. Whether the system be that of the direct or alternate current it will be possible to obtain power by means of electric motors from this source and no doubt this source of power will be largely used in surgery as it already is in dentistry. It will also be possible, though perhaps dangerous, to make use of these currents directly or indirectly in ordinary medical work. It is usual for the current to be so distributed that there is a difference of potential of about 100 volts maintained between the mains, no matter what current in moderation is taken out. In the case of direct current distribution no doubt the best method of utilizing the current so supplied is to charge accumulators with it arranged in series, and these can be rearranged according to the principles set out in Chapter III. to suit the work in hand. But when alternate current is supplied this is not feasible. Neither would it be practicable in many cases to use the current direct, inserting sufficient resistance to keep it down to a manageable size, since by this means much energy would be wasted. For example, if it were required to heat a cautery of resistance ·1 ohm and taking 25 ampères it would be necessary to insert in the circuit a resistance equivalent to 3·9 ohms and the energy used in heating the cautery would be but one-fortieth of that spent in uselessly heating the rest of the circuit. Recourse is therefore had to *transformers*.

118. **Transformers.**—The action of a transformer will be understood by a reference to § 76, in which that of the induction coil is described. In that paragraph it was explained how the passage of an interrupted current of moderate electromotive force in the primary of the coil caused an alternating current of high electromotive force in the secondary coil.

By the principle of the conservation of energy we see that, making no allowance for loss from heating or faulty design of the coil, the energy expended in the primary is equal to the energy furnished in the secondary, hence in practice it is found that the electrical work of the secondary coil is somewhat less than that expended in the primary. Now the work that a current can do is expressed by

$$W = E\,C\,t$$ (*see* §§ 54 and 70).

Hence we should expect the product E_sC_s, *i.e.*, electromotive force into current in the secondary to be slightly less than the product E_pC_p for the primary, or, not considering loss, at best equal to it. We therefore see that if E_s is greater than E_p, C_s must be correspondingly less than C_p.

Now if the current had been driven into the long secondary coil which would then be the primary, a similar induction would take place, and, the same relation of work holding good, the induced electromotive force in the former primary coil, now acting as the secondary would be far less than the inducing electromotive force, but the current would be proportionately greater. What is lost in electromotive force is gained in current. Thus it is possible by the intervention of an instrument made on the plan of an induction coil used the other way about to transform a small alternating current at one hundred volts into a large current, also alternating, at say, ten volts. Such an instrument is called a transformer. The analogy of a large mass moving with a small velocity, and a small mass moving with a great velocity, may help to make this clearer. The impact of either system might be made to be the same, just in the way that the energy of a small current at high electromotive force may be the same as the energy of a large current at low electromotive force.

It is not probable that at present transformers will be much used in medicine. In surgical practice, however, they are just now coming into use for lighting surgical lamps, and for the heating of cauteries. In districts which are supplied with alternating currents for electric lighting purposes small specially designed transformers promise to be very useful.[*] Probably, however, the above short account of them is sufficient.

119. **Medical induction coil.**—We pass naturally from the consideration of transformers to that of induction coils for faradic treatment. Sufficient was said in § 77 of the obsolete form of so-called "medical battery" which would now be called a magneto-machine. Various forms of this machine are figured in the instrument makers' catalogues, but they are hardly of use to-day, unless occasionally for a long continued course of faradism, when the patient himself might find it more convenient to use than a battery and coil. In § 76 a short account of the Induction or Ruhmkorff coil was given with a slight sketch of the theory of its action. The coils used for medical purposes only differ in one essential from the coils described there, viz., they are not as a rule fitted with a condenser. In other respects the nature and action of the medical coils are identically the same as there described. They merely differ among themselves in the method used for increasing or decreasing the electromotive force in the secondary. This resolves itself into varying the coefficient of mutual induction between the primary and secondary. The figures given show one or two of the methods in use.

Fig. 46 is a plan of the disposition of the wires in an induction coil, and fig. 47 shows an actual coil. The lettering is the same in both of the figures. One pole of the battery is connected by the wire shewn, to the binding screw A. The current then passes by the adjusting screw B, the vibrator H, and the support K to the horse-shoe magnet D. After traversing this the circuit branches, one wire passing to the binding screw P, the other leading to the primary coil, the return wire from which again branches, one wire lead-

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[*] "Lancet," vol. i., 1891, p. 292.

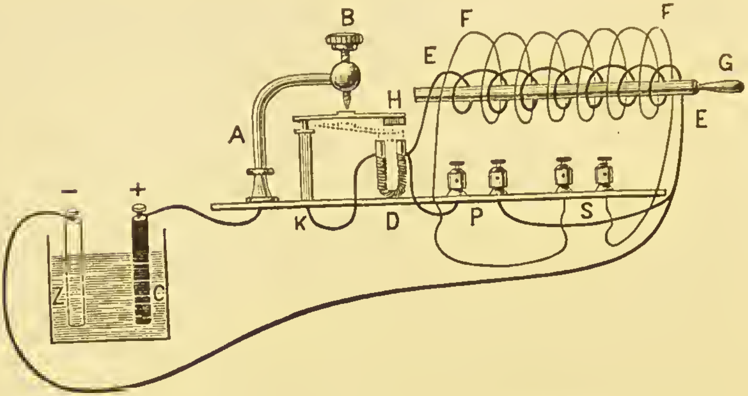

FIG. 46.—Arrangement of wires in an induction coil.

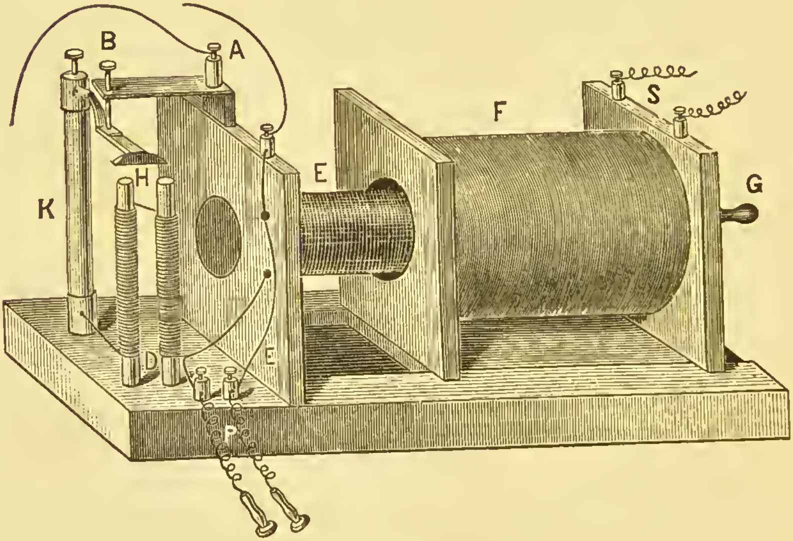

FIG. 47.—Induction coil.

ing to the second binding screw at P, the other to a binding screw which is in connexion with the other pole of the battery. The two binding screws at P are thus in connexion with the two ends of the primary coil and by means of electrodes attached to them the patient may be treated with the extra current of this coil, *primary current* (§ 75). The secondary coil F is wound on a separate hollow bobbin and has its terminals at S. This bobbin is made to slide like a sledge on guides so that it can be made to partially or completely surround the primary coil. At G a handle is seen attached to the iron core which can slide in and out of the primary coil, and so further regulate the induced electromotive force set up in both the primary and secondary, by varying their coefficients of self and mutual induction.

Another and somewhat neater form of sledge coil is shewn in fig. 48. The general plan of construction is

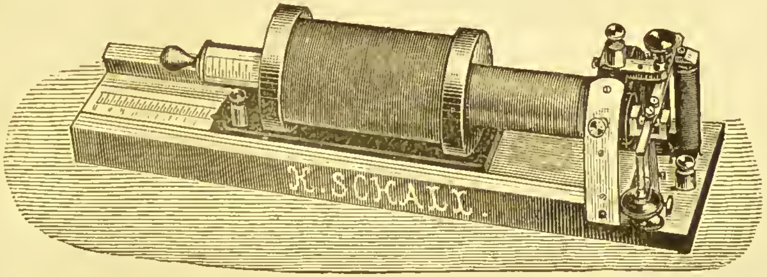

FIG. 48.—Induction coil.

the same as in the last figure with the addition of divided scales by which the relative positions of primary, secondary, and core can be recorded and results verified. It must be borne in mind that the readings of the scale are not at all in proportion to the electromotive force of the current induced in the coils, they merely make it easy to reproduce a given condition at will.

To obviate the necessity for withdrawing the core, many coils are fitted with a brass tube which slides between the core and the primary coil. This has the effect of shielding the core from the current in the primary coil, consequently the gradual withdrawal of the tube produces an increase in the number of lines of force in the core, and so increases the induction effects in both coils.

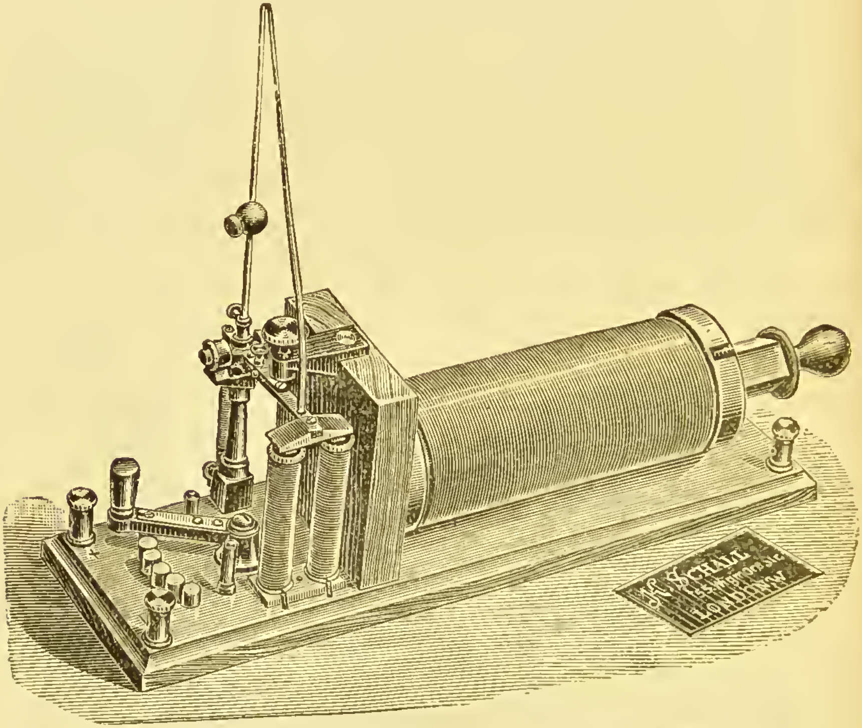

Fig. 49.—De Watteville's primary coil with interrupter.

In good coils there should be a method of adjusting the period of vibration of the hammer and with it the rapidity of alternation of the induced current. Dr. de Watteville has devised a coil consisting of a primary only, with a very ingenious method of regulating the speed of the contact breaker; this is shewn in fig. 49.

It will be seen to consist of an inverted V of stiff wire attached to the ends of the contact breaker, and having on one arm a small sliding weight which can be clamped by a thumbscrew at any position, thus altering the balance of the hammer and changing its rate of vibration in a manner similar to that used in a metronome. This coil has also a key by which the length and number of turns of the wire in use can be altered to suit the circumstances of the case.

120. **Primary and secondary currents.**—The physiological effect of the faradic or induced current is essentially different to that produced by the continuous current.

It will be worth while to devote a few lines to a consideration of the reasons for these differences. Simply stated, faradic currents may be looked upon as intermittent currents of short duration and of high electromotive force. In the case of the induced current in the primary, as in that of the secondary, the currents are not merely rapidly interrupted but alternating in direction, although the physiological effect of the alternating components may be very different from one another, and this difference is not that due to the difference in direction of the currents, but is rather due to the more abrupt rise of current at break than at make, so that the shock obtained from the coil is greater at break than at make.*

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* Students often find a difficulty in understanding why an induction coil should give a greater stimulus at break than it does at make, while with a simple continuous current interrupted by hand, the effects at make are greater than those at break. From the above it will be clear that the differences are due in the case of the induction coil to the mode of action of the apparatus, while in the case of the continuous current the difference is rather due to the properties of the nerve stimulated.

The general impression which prevails that the current of the primary coil is less painful than that of the secondary, is founded upon the vaguest ideas as to the action of the two coils. As coils are usually made of comparatively few turns in the primary and of many turns in the secondary, the co-efficient of self-induction of the primary is generally much less than that of mutual induction between the primary and secondary. Hence for a given inducing current in the primary, the physiological effect of the induced primary current or extra current is less than that of the secondary current. Thus it may happen that in any given coil the effect of the secondary current may be too intense for the purpose required, and it may be more convenient to use the current of the primary coil.

But little attention has been paid to the differences between the physiological actions of the primary induced current, and of the current of the secondary coil. Duchenne made a few experiments and observations, and since his day not much has been added. He compared the two currents by graduating their strengths until both produced the same degree of muscular contraction, and then, observing the sensory effect, he determined that that was greater in the case of the secondary coil. He also found that the secondary current readily threw into contraction other muscles besides those to which the electrode was applied, while the effects of the primary current were more localised to the part in contact with the electrode, and this great diffusion of the effect of the secondary current led him to say that it had a greater power of penetration than the primary. He also made other experiments to prove that this effect of the secondary was something peculiar, and not merely a result of its high "tension," but as a matter of fact his experiments merely showed that the current induced in a long secondary coil is able to force its way through a bad conductor; this is just what would be expected from its high electromotive force.

It may be mentioned incidentally that very many of the medical coils sold are not strong enough in themselves, or are so badly contrived as to be quite unfit for the wear and tear of regular use. It is of great importance to have a well made coil, and the cheap forms as well as the very light and portable ones are little better than toys.

CHAPTER VI.

ACCESSORY APPARATUS.

Conducting wires. Cautery wires and surgical lamps. Binding screws. Electrodes. Current collectors. Commutators. Regulation of current. Resistances. Wire rheostat. Water rheostat. Galvanometers. Testing instruments. Voltameters. Water voltameter. Copper voltameter.

121. **Conducting wires.**—The conductors or leads by which the current is conveyed from the battery or other generator to the place where it is to be used are generally of copper wire or flexible stranded copper cord. Copper is used because it is the best conductor among metals with the exception of silver, which indeed is not very much better and is out of the question on account of its cost. Any sort of copper wire, bare or covered, may be used to convey the current but it is best to use insulated wire and so avoid any risk of short circuiting from the wires coming into accidental contact. Wire, plain or stranded, may be bought insulated either with cotton or silk or india rubber, and for cases where the current has to be conveyed some little distance (1 to 10 yards) it may be convenient to use double conductors made of two insulated wires twisted together.* It is sometimes convenient to keep wires coiled up in a spiral form, these can be pulled out at the convenience of the operator and have a neater appearance than uncoiled wire.

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* In this case it is well to mark the ends, so that there may be no difficulty in recognising the positive and negative wires. A pole-tester (§ 116) will prove useful for this purpose.

In the majority of cases the size of the wire used is immaterial as the conductivity of copper is so high that a very thin wire will carry a current far larger than is required for purposes of medical galvanism without any sign of heating, and the resistance of such wire is infinitesimal compared with the resistance of the body. Even when small lamps are to be lighted unless very fine wire is used the size is unimportant. But for the large currents that are necessary to heat cauteries, the matter takes a very different aspect. We have seen a thin copper wire, improperly used for connecting an accumulator with a cautery, grow so hot as to melt off the gutta-percha insulation throughout its whole length, while the resistance of the circuit was so increased by the use of this unsuitable lead that the cautery was not heated, although, had a proper lead been used the battery power would have been sufficient.

This is an extreme case and only likely to occur with large cautery burners which need a very large current to heat them, but it affords an useful example of the need of attending to the conducting wires. From the following short table the best size of wire to be used for the connexions of a cautery requiring any number of ampères up to 60 can be found.

If this table be followed it will be found that the leading wires will never rise in temperature by more than about 15° C and the loss will be infinitesimal. The table is calculated on the assumption that the copper wire to be used has a conductivity of 95 per cent. of that of pure copper. Sometimes it is desired that a wire conveying a current should conduct badly, then such metals as steel, platinum or German silver and thin wires are used. We shall consider this point again in speaking of resistance coils.

Current in Ampères.	Standard wire gauge	Diameter in Millimetres.	Resistance in ohms per metre.	Loss in watts per metre.
60	No. 2	7·0	·00046	1·64
50	3	6·4	·000557	1·41
40	4	5·9	·000655	1·10
30	6	4·9	·00092	·82
20	8	4·1	·00137	·55
10	11	2·9	·00279	·26
5	14	2·0	·00561	·13
4	15	1·8	·00670	·12
3	16	1·6	·00813	·08
2	18	1·2	·014	·06
1	20	0·9	·0279	·03

122. **Cautery wires and incandescent lamps.**—Cautery wires are almost always of platinum; steel is, however, sometimes used and answers very well. The resistance of steel is rather higher than platinum, especially at a red heat, consequently less current is required to heat a steel cautery wire than one of platinum of the some size.

Preece[*] has determined the current needed to heat to redness wires of one millimetre in thickness, and has found that platinum requires 40 ampères, and iron 24, thus giving iron a considerable advantage from the point of view of current expended. Platinum, however, has the advantage that it is not oxidizable, consequently is not affected by being repeatedly heated, and it is more flexible than steel while it is sufficiently stiff, and has a higher fusing point.

The resistance of the cautery burners in common use may vary between ·025 and ·04 ohm, but it is impossible to know the resistance of any given burner without testing it experimentally. The current required for such cauteries as these varies with the thickness of wire used in them, it may be from 10 to 25 ampères, some very large ones for special purposes have been made that take as much as 40 or 50 ampères.

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[*] "Proc. Roy. Soc.," vol. xxxvi., p. 464.

Surgical incandescent lamps have a short carbon filament which glows with the passage of the current when that reaches from ½ to 1 ampère: they are very small and even to yield the small amount of light for which they are intended they must be heated far beyond what would be considered right with lamps for ordinary lighting purposes; this is a severe tax upon the filament and renders their life very short. A good commercial lamp is expected to last for at least a thousand hours and requires the expenditure of about four watts per candle power. They are made to carry from ·25 to ·8 ampère but surgical lamps may consume rather more current, one ampère or even more. The larger lamps have a longer filament, roughly in proportion to their candle power; the extra length of filament from its high resistance requires a greater electromotive force to drive the same current through it, so that a 32 candle power lamp though it carries the same current in ampères as a 16 candle power lamp requires twice the electromotive force or as it is usually expressed consumes twice the number of watts. It will be remembered (§ 70) that *watt* is the term used by electrical engineers for the energy expended by a current of one ampère between two points whose potential differs by one volt.*

When a lamp is pushed to give more light than that for which it was designed, its production of light for the time is at a more economical rate, that is to say, fewer watts per candle power are used up. Hence a surgical lamp as usually treated gives a candle power rather greater than that reckoned for the watts expended. They may be well lighted if only required for a short period by three or four bichromate cells or even by six large Leclanché cells* in series, this arrangement of cells will give respectively about 6 and 8 volts, an electromotive force sufficient for a small lamp; the smallest lamps, used in the cystoscope or laryngoscope, only require about four volts, and the larger ones five or six volts to give a proper light.

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* An example may help to illustrate this, for instance, a certain lamp of 16 candle power required ·71 ampère and 100·4 volts, the rate of expenditure of energy in watts was therefore 100·4 × ·71 = 71·3 watts, that is, 4·45 watts per candle.

123. **Binding screws.**—The current is taken from the battery terminals or poles. These usually have binding screws by means of which the leading wires are attached. Binding screws are also used to connect the conducting wires to the instrument to which the current is to be led. It is of the highest importance that at all the points where connexion has to be made it should be thoroughly and well done. All binding screws must be kept scrupulously clean, and the larger bearing surface they have the better; the ends of all wires must also be freshly scraped when connexion is to be made, so that there may be true metallic contact at every point of the circuit. A thin film of dirt or metallic oxide at a connexion interposes an incredibly high resistance into the circuit. Faulty connexions are one of the commonest causes which throw electrical apparatus apparently out of gear, and although it is not hard to detect the fault by careful examination (§ 78), yet only too often much difficulty is found, and in consequence the battery is condemned, or the services of the instrument maker are called in. It need not be said that this is the wrong way of doing things, for everyone using a battery should make himself familiar

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* A special form of Leclanché cell for this purpose is made by the India Rubber Co., Silvertown, Essex.

with the proper management of it, in order to avoid the expense and annoyance of perpetually putting it into the hands of an instrument maker.

The most perfect metallic connexion is made by soldering the wires to the terminals of the batteries or instruments to be used, but this is impracticable in most cases, since it makes it very troublesome to dismount the battery, and in general more than one set of instruments has to be worked from one battery. As a matter of fact with moderate care no difficulty need occur from faulty contacts in binding screws. Unfortunately many instrument makers put special terminals on to the wires they send out, which are suitable for making connexion with their own batteries and instruments, but will not fit those of any other maker.

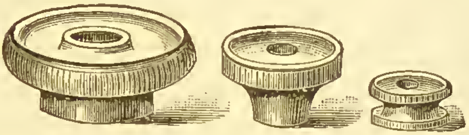

FIG. 50.—Binding screws.

These are seldom of any advantage, and should be discarded, for a plain ending to the wire is the best. It is advisable, for the sake of neatness, to use but one form of binding screw, and that which is represented in the figure is simple and convenient. There are of course many other forms in constant use, and a few minutes may be well spent in inspecting an electrical instrument maker's stock. The best way to connect a wire with a binding screw, of the type in the figure, is to bend the well cleaned wire round the shank of the screw and then screw the nut down tightly upon it.

124. **Electrodes.**—The terminals by which the current is applied to the place where it is to be used are

called Electrodes. The word electrode is also used to describe the terminals by which the current leaves the battery or enters any instrument. The special terminals used in galvanism and faradism are also called rheophores, a term which has also been applied to the conducting wires, and here we may once for all protest against the use of too many unnecessary terms. Such words as rheophores for electrodes or conducting wires, rheostats or rheochords for resistances or resistance coils, rheotropes for commutators, and rheotomes for contact breakers, are, as a rule, not wanted, and the words in common use among electricians are enough for all medical purposes. The variety in nature and shape of the electrodes used in medical practice is immense; it is necessary, however, to describe some of them. The old fashioned brass handles and wet sponges are now almost wholly abandoned, except perhaps for the purpose of rousing people from a state of poisoning by alcohol or opium, and the favourite form of electrode at present is a convex disc of gas carbon or of nickel plated metal screwed into an insulating (wooden) handle and covered over with wash-leather or amadou.

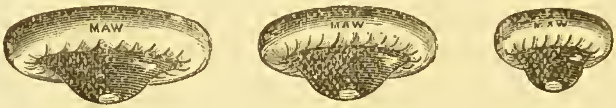

FIG. 51.—Carbon disc electrodes.

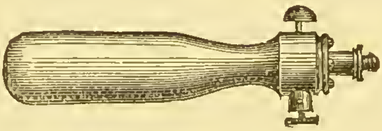

FIG. 52.—Handle for electrode.

The handles are of more or less elaborate design, some being fitted with keys for closing the current or for opening it, or even for reversing it, one or two of these handles are figured here, and many more will be found in the instrument makers' catalogues.

The greatest care must be exercised to prevent risk of communicating contagion through the medium of the electrodes, on this account metal is better than carbon ; the amadou, or flannel, or wash leather covers should be often renewed, and as far as possible a separate set should be kept for each patient. In fact it is advisable in many cases to use an extempore covering of absorbent cotton or to have loose woollen covers like glove fingers which can be quickly slipped on and off the electrodes, and to keep them in carbolic solution, or to boil them occasionally.

Several sizes are required. *Professor Erb* has suggested the adoption of electrodes of standard sizes because

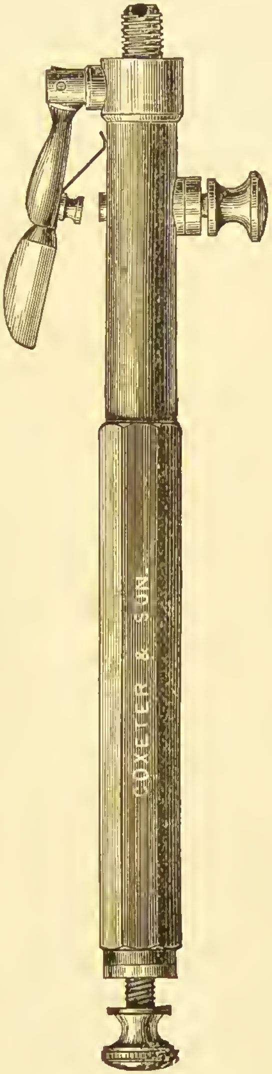

Fig. 53.—Handle for electrode with key for making and breaking circuit.

the density of the current and the effective resistance of the surface at the point of entry depends upon the size of the electrode, that is to say, the area from which the current passes to the patient. For different effects one may desire at one time a current diffused over a large surface of entry, and at another a current concentrated at a small surface. In the operation for the removal of superfluous hairs by electrolysis, the indifferent electrode is large and the local effects on that part of the skin which it touches are imperceptible, but the active electrode is a fine platinum needle, and the density of the current at its point is such that strong local effects are produced where it touches the skin even when the current is only three milliampères. By

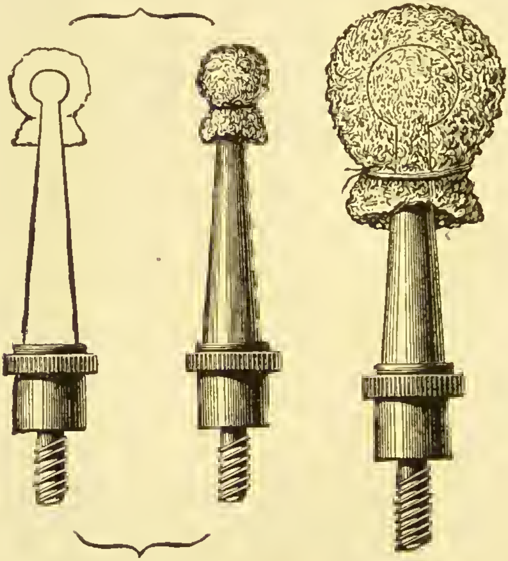

FIG. 54.—Small metal electrodes.

using standard sizes too one can more readily convey to others a correct idea of the current density used in any particular case. *Erb's* standard sizes are the following :—

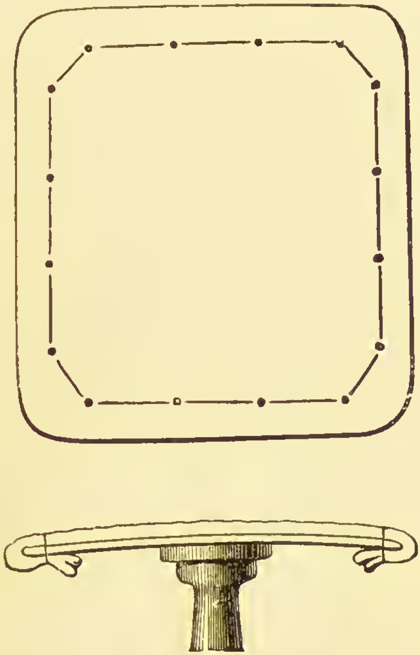

FIG. 55.—Large metal electrodes.

Name.	Diameter of disc.		Area of surface.	
Smallest	·5 cm.	·2 inch.	·25 sq. cm.	·04 sq. in.
Small	1·5 ,,	·6 ,,	1·8 ,,	·28 ,,
,,	2 ,,	·8 ,,	3·14 ,,	·5 ,,
Normal	3·5 ,,	1·4 ,,	10 ,,	1·5 ,,
Medium	5 ,,	2 ,,	20 ,,	3 ,,
Large	7·6 ,,	3 ,,	50 ,,	7·6 ,,
Very large	11·2 ,,	4·4 ,,	100 ,,	15 ,,
,,	13·3 ,,	5·25 ,,	150 ,,	23 ,,

These sizes do not cover all the variations which are required for medical practice, for in *Apostoli's* treatment of uterine disease by the galvanic current the indifferent electrode is larger still, while, for nævi and epilation, electrodes made of fine sharp needles are used. An obvious objection to this series of sizes is that they are not very regular in scale, and that for the important size of "small" electrode two alternatives are proposed. Moreover the numbers are difficult to remember; it would be quite as useful and more convenient to adopt a series of circular electrodes numbered according to their diameter in centimetres from 1 to 12. It will be seen in Chapter VIII. that another size is proposed by the same author (*Erb*) for use in testing the contractility of muscles, namely one of 4 cm. diameter.

The more special forms of electrode will be described and figured in the chapters which deal with the particular operations in which they are used.

In some medical applications both the poles of the battery are used equally, and in that case the electrodes at the two poles may be similar, but more often the current is brought to the affected part from one pole, which is then known as the "active electrode," and may be positive or negative according to the treatment required, the circuit being completed by the application of the other electrode "indifferent electrode" to some remote part of the body; under these circumstances the active electrode may require a handle for its proper manipulation, while the indifferent electrode is most conveniently arranged as a simple metal plate, which can be applied to the surface of the body and left there during the treatment. It is generally an oval plate of pure tin about three inches long; this metal is harmless, light and sufficiently flexible, and can be bent to fit the surface of the body. Plates of lead are not so good, nor so convenient, their use seems to render the wash leather covering them very harsh and dry, so that it is not easy to moisten the covering uniformly. On one side is a binding screw for the attachment of the battery wire, and the other side is covered with a smooth piece of amadou, or wash leather, which can be moistened with water or salt solution before use. It is cleaner to have a sheath or pocket with one side waterproof, to contain the electrode (fig. 56), this will serve to protect the patient's clothes from being wetted without interfering with the passage of the current. Bare metal must never be applied directly to the skin unless electrolytic effects are wished for, the current is very much more painful when it enters the skin from a metallic surface

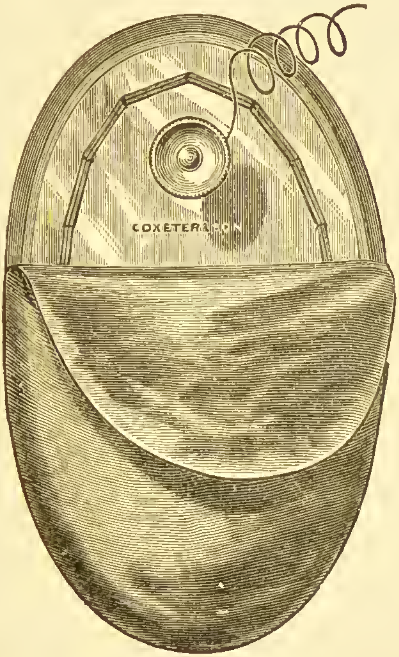

FIG. 56.—Tin electrode and sheath.

than when it first passes through a layer of moist badly conducting material.

The indifferent electrode may be slipped between the clothing and the skin, the pressure of the clothes will then suffice to keep it in place, or if the patient is lying down the electrode may be put underneath the shoulders or the buttocks, or it may be held against the skin by the patient himself or by an attendant. In either case the operator is able to give his whole attention to the other or active electrode. Care must be taken to see that the contact of the indifferent electrode with the skin is well maintained, and that no dry clothing lies between, sometimes, especially with children, it may be fastened on by a few turns of a bandage, or by a soft garter or belt of some kind. The precaution should be taken of seeing that the proper side of the sheath and the proper face of the electrode are together, for the waterproof side will not conduct.

Lately a new form of indifferent electrode has been brought out under the name of the "adhesive electrode;" it consists of a flat piece of composition, containing gelatine and oxide of zinc, when its surface is moistened with warm water and then applied to the skin it adheres fairly well; on the back of the composition is a layer of tinsel, waterproofed over, and a tag of the same material makes connection with the battery wire by means of a spring clip. They are very cleanly and good, and can be had of any convenient size.

125. **Current collectors.**—Medical batteries for galvanic treatment are made up of a large number of cells (20, 40 or 60 arranged in series), but the number of cells to be used for different cases varies very much. On this account a quick and simple plan of altering the

number of the cells included in the circuit is required so that the current may be readily increased or diminished to suit the needs of each case by switching cells in or out of circuit. The plan is as follows :—

In the diagram, fig. 57, six cells are shown numbered I. to VI., they are joined in series, and from their connexions wires are led off to seven corresponding studs numbered 0 to 6. It may be seen that a moveable metallic arm springing on to stud No. 1 will throw one cell into circuit between the binding screws marked + and −, and similarly when the arm is placed on any other stud it brings into the circuit the number of cells shown by the figure marked against the stud.

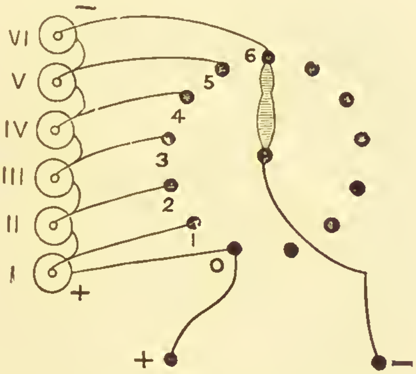

FIG. 57.—Plan of single current collector.

This is in brief the principle of the current collector, as applied to medical batteries, the stud marked 0 being connected with one pole, say the positive pole of cell No. 1, and leading to a binding screw marked +, stud No. 1 being attached to the negative pole of the same cell and when the moveable arm touches stud No. 1, the current passes along it and from there goes to the other binding screw of the battery marked as shown in the figure. Cell No. I. only is then included in the circuit; if the pointer be transferred to another stud, numbered let us say 6, then six cells are in circuit and are being used.

A more complicated current collector has been devised, by means of which the current may be taken from any cell or any group of cells commencing at any point, the advantage is that the cells can be used equally, so that the wear and tear is equally distributed. In the single collector the first cells are always drawn upon, and are likely to run down before the last cells, which are only needed occasionally. With the double collector if six cells are required not only could cells 1 to 6 be chosen but cells 3 to 9, or 6 to 12, or 12 to 18 or any other set of 6. With the single collector the first cells must always provide current and cell No. 12 can only be used when eleven cells are insufficient. Accordingly, with a single collector, the last cells of the series are very seldom called on at all, while the first cells have to do duty every time the battery is used. This objection to the single collector has been partly over-

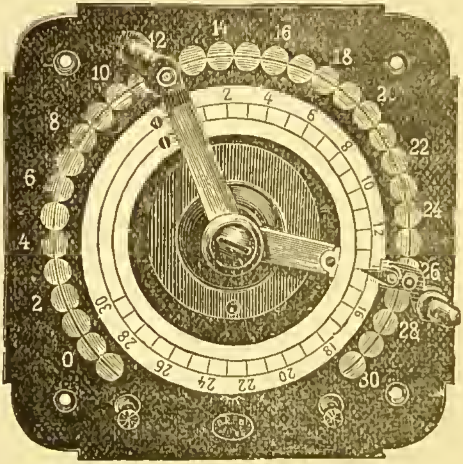

FIG. 58.—Double collector.

come by *Mr. Coxeter*, who has an arrangement for dividing the whole number of cells into three or four groups by a moveable connecting wire, but it is not so precise a method as the double collector affords. Another advantage of the double collector is that with its aid the working of every cell of the battery can be separately tested; the double collector, however, is rather more expensive. If in the figure of the single collector (fig. 58) the wire leading from cell No. I. to the stud numbered 0 were taken instead to a second arm pivoted on the same axle but electrically insulated from the first one and capable of independent movement, and were led thence directly to the binding screw marked + it can be seen that with the two arms on the studs 3 and 6 the current would be taken from cells IV., V. and VI. only, that is to say the group of cells IV. to VI. would supply the current to the circuit. In like manner any number of consecutive cells from one upwards could be picked out from any part of the whole series. It is usual for one of the arms to carry a circle so divided and numbered as to read off directly the number of cells in use.

The studs of current collectors must be of good size, and the pointer just broad enough to touch two at once, that the number of cells in the circuit may be increased or diminished without breaks of current and unpleasant shocks at the moment when the pointer moves from one stud to the next. At the same time care must be taken that the moveable pointer of any collector is not left for any length of time in contact with two studs at once, for when it is in that position one cell is short-circuited and its energy is being ruinously wasted.

When it is wished to test the working of a medical battery, the electrodes should be placed in a bowl of water, some little distance intervening between them, and the pointer must then be gradually moved round the studs, the galvanometer being watched carefully. If the battery is in proper order it will indicate a regular rise of current step by step, for every cell added to the circuit. If the galvanometer needle falls to zero as the pointer is passing from one stud to the next, it indicates that the current is broken at that moment, and if a patient were in circuit, he would receive an objectionable shock. If the needle falls to zero when the pointer is on a stud, it shows that the connexion between that stud and the battery is faulty.

It is a bad practice to try to test a battery by connecting the terminals by a direct metallic contact except through a coil of high resistance, 1000 ohms or so, otherwise the strength of current may be so great as to damage the galvanometer by throwing the needle off its pivot, and it will probably be too large even with one cell for a galvanometer graduated in milliampères to give readings of it; if no resistance coil be at hand the plan of putting the electrodes into a bowl of water will usually suffice to reduce the current in the circuit to a quantity which can be measured in milliampères.

126. **Commutator or current reverser.**—An apparatus for reversing the direction of the current in the external portion of the circuit is indispensable for some medical purposes. It is not possible to make an examination of the reactions of nerve and muscle without one. There are many forms in constant use, but one only will be described, as it has seemed to the authors to be the most convenient in medical work. This pattern is shown in the accompanying figure (fig. 59); it was devised by *Ruhmkorff*.

It consists of a cylinder of vulcanite M, having at each end a metal cap or ferrule C, D, and supported between two uprights in such a way as to revolve easily about a horizontal line, each end is connected to a binding screw A, B, and each metal cap is prolonged in the form of a cheek E, F, along one side of the vulcanite cylinder for two-thirds of its length. On either side of the cylinder springing against it, are two pieces of metal I, and L, connected with the terminals of the battery. When the cylinder is turned by means of the handle Z, either of the metal cheeks can be brought into contact with each of the springs I, L. The positive pole of the battery connected say with L, can thus be brought into connection with either the binding screw at A, or at B, so that the current can be made to pass in either direction at will round the external portion of the circuit between A and B. The + and — signs on the vulcanite cylinder indicate the polarity of the binding screws; in the position shown A is positive, a half revolution of the cylinder alters A to negative, and therefore the reverse side of the cylinder which then comes into view will have the + and — signs transposed also.

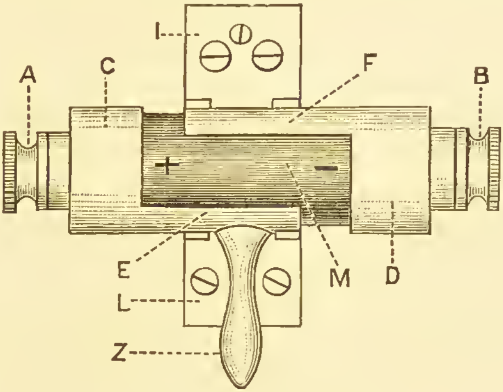

FIG. 59.—Commutator.

127. **Regulation of current.**—When the current is regulated by the method described in § 125, it will be seen that, neglecting the resistance of the battery, the electromotive force is the only thing altered in the circuit. But by Ohm's law we know that the current is numerically equal to the electromotive force divided by the resistance of the circuit, so that it might be regulated by introducing or removing resistances, the electromotive force being kept constant. In some cases it is more convenient to regulate by this method. In general, when the total resistance of a circuit is large, it is more convenient to alter the electromotive force than the resistance in the circuit. Thus, suppose a circuit has a total resistance of 3000 ohms, and is acted on by twelve cells of 1·5 volts each, there will be a current of six milliampères; if now it is required to double the current it is easily done by adding twelve more cells, taking for granted that their internal resistance may be neglected, but if it were desired to make the alteration by reducing the resistance of the circuit it would be necessary in order to double the current, to take out a resistance of 1500 ohms, which might be impracticable. When it is desired to increase current by taking out resistances, it is of course requisite that the resistances to be removed must first be connected up in the circuit before the commencement of the operation. If the total resistance is small this can be done, and in such cases the current is most easily governed by variable resistances in the circuit. Thus, suppose a circuit made up of a cautery burner whose resistance with its leads amounts to ·01 ohm, and an accumulator whose electromotive force is two volts and internal resistance ·002 ohm; the current could be well governed by having a variable resistance up to ·5 ohm in the circuit. When

the current was turned on with full resistance it would amount to about 3·9 ampères, and by reducing the variable resistance to ·098 ohm a current of 20 ampères would be given which would probably suffice to heat the burner.

There is one advantage that belongs to this method of regulating the current, viz., all the cells in a battery are in use the whole time and equally, so that there is no liability from the method of use for one cell to run down and require recharging before another, but even this advantage will not compensate for the cost of high resistance coils and the inconvenience of using them.

128. **Resistances.**—Resistances or rheostats* are made up in many forms. A figure of a resistance box made up of wire coils and arranged as a Wheatstone's Bridge was given in § 67. The coils are generally made of a length of insulated German silver wire doubled on itself (fig. 60) (that the coils should have no self induction) and coiled on a bobbin. Coils are then arranged in the following order:—1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1000, 2000, 2000, 5000 ohms respectively, so that any of them can be thrown in or out of circuit by removing or replacing plugs on the top

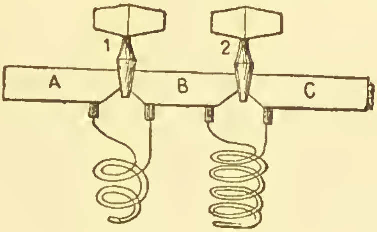

FIG. 60.—Plan of resistance coils.

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* The word "rheostat" is perhaps the least objectionable of those referred to in § 124, solelv however because it has been hallowed by use.

of the resistance box. It will be seen that with the above arrangement of coils any resistance from 1 to 10,000 ohms can be put into circuit. Such resistance boxes are capable of the very highest accuracy, but as a rule this is not required in medical work, and they are damaged if any large current is sent through them, besides which they are exceedingly costly. They are only likely to be required in large institutions, where it may be necessary to find resistances of apparatus or the electromotive force of batteries with high accuracy.

129. **Wire rheostat.**—The resistance coil that will be most frequently in the hands of the medical man is sometimes known as the "wire rheostat." It is very convenient in cases such as the example given above, in which there is a small external resistance only in the circuit, and a large current is to be regulated. It usually consists of a long open corkscrew coil or helix of moderately thick uncovered German silver or other wire, such as platinum-silver alloy, of high specific resistance (§ 63). The current is led in at one end of the helix and a metal sliding piece which can pass from end to end of the coil forms the other terminal. The resistance interposed is easily seen to be proportional to the number of turns of the helix between the end attached to the terminal and the sliding piece. The form of this resistance is favourable to cooling, thus a much larger current may be driven through it than through a coil of covered wire not open to the air.

130. **Water rheostat.**—Another resistance apparatus sold to medical men is the "water rheostat." It consists of a glass cylinder, watertight and filled with water or some saline solution, it terminates below in a metal foot B and binding screw, and a metallic rod moving stiffly passes in from above through a collar, A,

and this carries the other binding screw. When the rod is pushed quite down it touches the base of the tube, and the circuit is completed through the metallic contact; when it is raised the current must pass through the badly conducting liquid. The resistance offered by the liquid varies with the length of liquid to be traversed and the nature of the solution, and the rod can be roughly graduated for the resistance of the liquid to be used. It will easily be seen that a drawback to the use of this form of resistance is the polarization likely to be produced by electrolytic changes in the liquid. Moreover at the moment when the metal sliding rod is separated from contact with the metal base of the tube, there is a sudden great increase of resistance in the circuit, and an unpleasant shock may be produced.

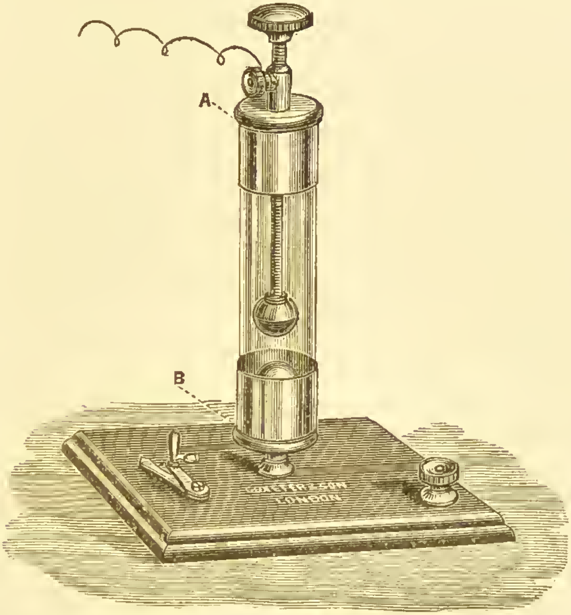

FIG. 61.—Water Rheostat.

Cheap resistances have been made of discs of graphite piled loosely in a tube and more or less pressed together by a screw to vary the resistance of the combination, these however are very unreliable. A high resistance for temporary use may be improvised by ruling a line with an ordinary lead pencil on ground glass and connecting the circuit with the ends of the line by means of pieces of tin foil. Other forms of graphite resistances have been devised for medical purposes, and in certain cases they are useful, as for example, to regulate induction currents.

131. **Galvanometers.**—It is generally of the utmost importance that the medical man shall be able during the course of an electrical operation to see at a glance what current is passing, and for this purpose a galvanometer is necessary. We may refer the student back to §§ 49, 50 for a cursory account of the theory of the galvanometer. Here we have to describe one or two that are in common use.

There are certain features that from the nature of the work they are called upon to perform are common to all galvanometers for medical purposes. The most important is perhaps the method of graduation. These galvanometers are invariably of the fixed coil or "tangent" form (§ 50) that is to say, the current indicated by any reading is proportional not to the angle of deflexion but to the trigonometrical tangent of that angle. Hence it is necessary that the circle on which the position of the needle of the galvanometer is read must be graduated, not uniformly, but so that the readings are angles whose tangents increase uniformly.

This may be practically carried out for any circle that it is required to divide as follows:—Let O (fig. 62) be the centre of the circle, at P draw a tangent to the circle and join OP. Mark off equal spaces PL, LM, MN, &c., along this tangent line and join each point to O the centre of the circle. These lines will make such angles with OP that their tangents increase by equal steps, and the points where they cut the circle will be the ends of arcs subtending angles at the centre of the circle whose tangents fulfil the required condition. If the galvanometer constant (§ 51) is such that a deflection of the needle from 0 to 1 indicates a current of n milliampères flowing in the galvanometer, then a deflexion to 2 will indicate that $2n$ milliampères are passing and so on. So that

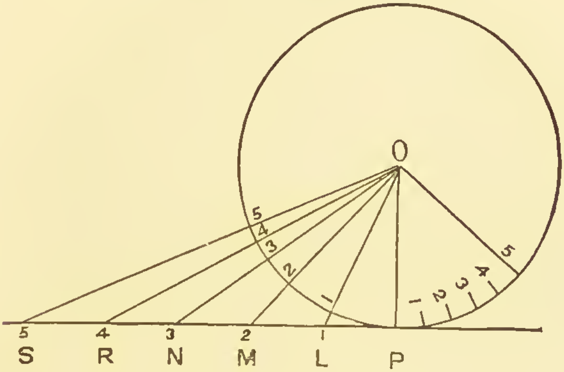

FIG. 62.—Graduation of galvanometer.

by suitably choosing the equal spaces that are marked off along the tangent line any galvanometer scale may be made to read in milliampères. This is called "calibrating" the galvanometer and the calibration of every galvanometer should be checked from time to time by the user. A method of doing this will be described in § 133 below.

A galvanometer calibrated to read milliampères may be called a "milliampèremeter" just as one calibrated to read ampères is called an ammeter. Medical men owe it to *Dr. De Watteville* that the milliampère has been chosen to be the standard for medical purposes, and for this it is a most convenient measure.

Many galvanometers are provided with a set of two or three resistance coils which may be inserted in parallel with the galvanometer coils, they are usually of such values that they only allow one-tenth or one-hundredth or one-thousandth of the whole current to pass through the galvanometer. In § 66 the necessary calculation was given by means of which the resistance of such a coil, called a shunt, for a galvanometer of any given resistance could be determined. The use of such a shunt is too obvious to need much explanation. Sufficient will be said in the account of *Edelmann's* large galvanometer below.

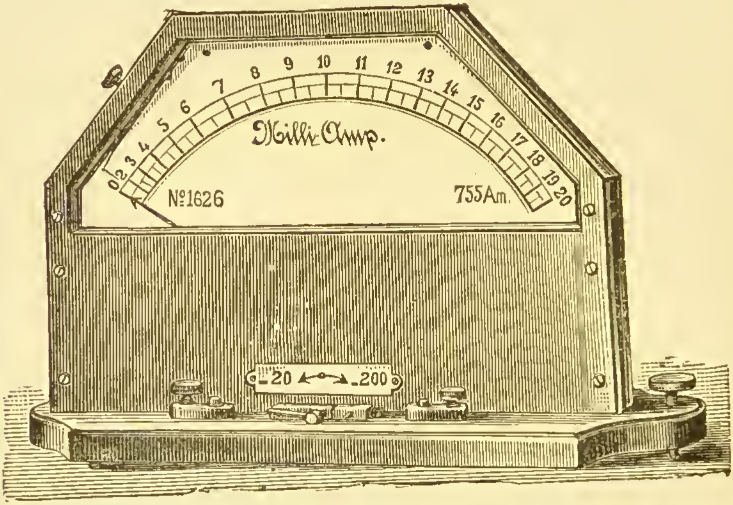

Fig. 63.—Vertical Galvanometer.

Galvanometers for medical use are invariably calibrated and marked to read in milliampères by the makers. Fig. 62 shews the appearance of a circle graduated at one part to read directly into current, as compared with one divided in equal divisions of arc.

Medical galvanometers may be conveniently divided into the vertical and horizontal forms. Fig. 63 shews one of the vertical type. It is easily read but does not always work very well, perhaps owing to a tendency to clog, from dust and dirt at the axis interfering with its movement. It is convenient in use, however, because it is not necessary to set it in a definite position with regard to the north and south line (magnetic meridian) at the place where it is to be used.

Fig. 64 shews a horizontal galvanometer of a form made by *M. Gaiffe*, and also explains the construction of the instrument. S S′ are binding screws, V V′ are levelling screws, D the base board, G the graduated scale in the case enclosing the wire coils, B and C the metal case of the instrument. The small screw at *v* moves the lever A which lifts the needle off its pivot when not in use. The pointer is made of aluminium for lightness sake, and is set at right angles to the real magnetic needle which is hidden inside the coils. Be-

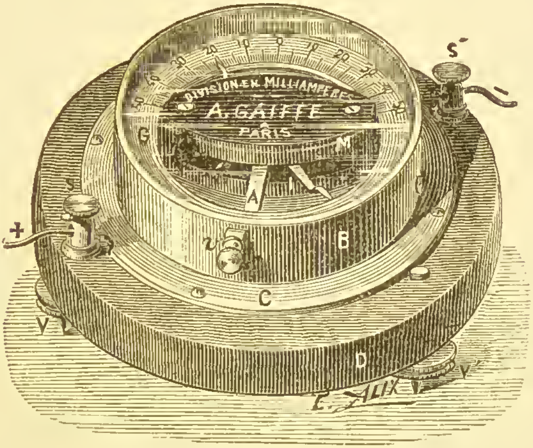

FIG. 64.—Horizontal galvanometer.

fore use the instrument must be so placed and levelled, that the needle comes to rest at the zero, and swings freely about that point. The magnetic needle then points along the magnetic meridian of the place where it is to be used.

This instrument as generally made is designed for measuring large currents only. It is calibrated to read up to 250 milliampères, and each division represents 10 or 20 milliampères, it is therefore not convenient for regulating small currents, but is the form most useful for the electrolysis of nævi, and for the electric bath.

Fig. 65 is a representation of *Edelmann's* large non-portable galvanometer which is a very convenient and beautiful instrument. At F is seen one of the three feet of the instrument with its levelling screw, M is the base board, G a short cylinder of glass covered by a glass top L, which is perforated at the centre for the needle suspension to pass through; these make a case for the instrument and keep it from dust. The magnet with its long straw pointer Z, the end of which is seen at W, is suspended by a cccoon silk fibre supported from a pin, which can be raised and lowered by a rack and pinion worked by the milled head, S. N is a wooden ring which supports the pillar down which the suspension passes. T is the scale, a cylinder of paper divided to read in milliampères. This arrangement of the scale is specially designed in order that the instrument may be read from a distance. At *a* and *b* are seen the wires which lead the current into and out of the galvanometer, the three small discs numbered in the figure 10, 20 and 30 should be numbered 10, 100, 1000, they are the heads of three screws by means of which shunts can be thrown in to reduce the proportion of current passing through the galvanometer to $\frac{1}{10}$, $\frac{1}{100}$ or

$\frac{1}{1000}$ respectively of that in the whole circuit, so that when one of these is in use the reading of the scale must be multiplied by 10, 100 or 1000, as the case may be, to give the whole current in the circuit.

It has already been mentioned that a galvanometer of so high a resistance that the resistance of a battery is

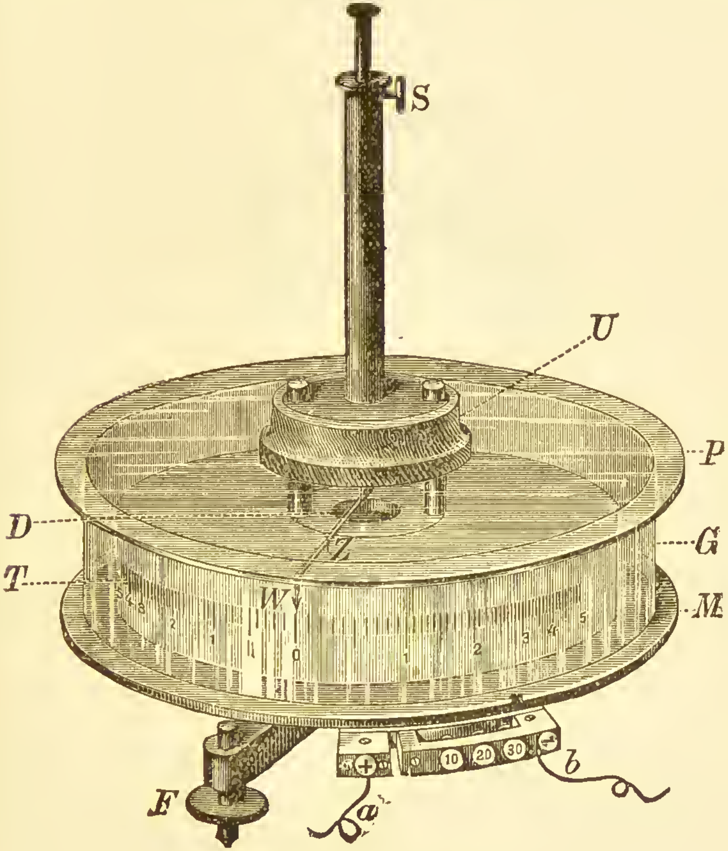

FIG. 65.—Edelmann's galvanometer.

negligible compared with it may be used for finding electromotive forces, and such a galvanometer is called a Voltmeter. Small voltmeters of this type are sold by electrical engineers for testing storage cells, and are calibrated up to about 2·5 volts. A figure is given of the one sold by the E. P. S. Company for testing their accumulators. The terminals of the instrument are connected with the rough ends of the small rod shewn, and these are pressed and rubbed against the poles of the cell to be tested, thus making a good connection. Such a voltmeter is a necessary adjunct to an accumulator (see § 113).

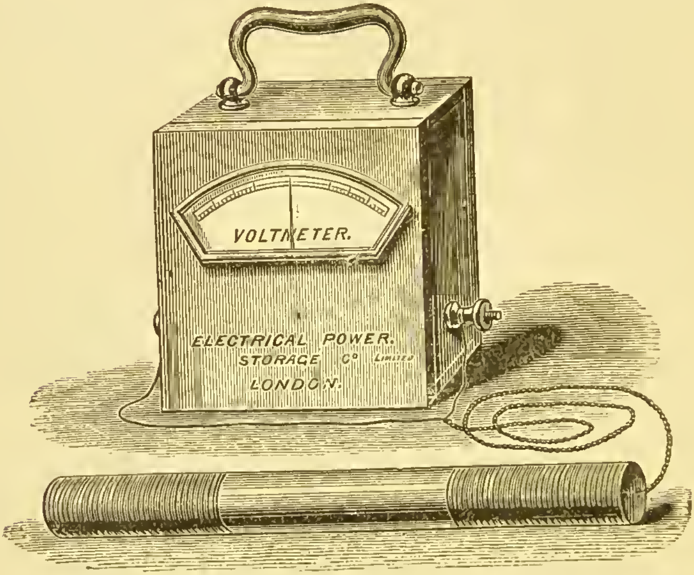

FIG. 66.—Voltmeter.

There are many other types of voltmeters for other purposes. *Cardew's* consist of a long strip of platinum iridium wire which is heated by the current, and expands, moving a pointer which indicates the expansion on a specially calibrated dial. *Ayrton and Perry's* is a coil or solenoid, which draws a soft iron core into it, and the movement is indicated on the dial by a very ingenious spring invented by them. All these instruments are calibrated by the makers to read in volts, but should be checked from time to time by the user.

132. **Testing instruments.**—All batteries and other electrical instruments should from time to time be tested, thus, it is advisable to know both the electromotive force and internal resistance of batteries in use. If a Post Office resistance box is at hand, so that the method of *Wheatstone's* bridge (§ 67) can be applied, the easiest method of finding a battery resistance is to couple up two cells in opposition to each other, and find their resistance in the same way that the resistance of a wire is found. Half the resistance of the combination may then be taken as the resistance of the battery. Or *Mance's* method as modified by *Lodge* may be used, this method is described in *S. P. Thompson's* "Lessons," or in *Balfour Stewart and Gee's* "Practical Physics," or in almost any book on electrical testing.

The electromotive force of a battery may be read off at once by using a suitable voltmeter, or it may be found by connecting up the battery with a galvanometer, and a known high resistance of several thousand ohms. The internal resistance is negligible compared with this, and if the resistance of the galvanometer be known we can find the electromotive force from the equation

$$C = \frac{E}{R} \text{ or } E = RC.$$

Thus, for example, a certain cell was connected up with a resistance of 900 ohms, and a galvanometer of 100 ohms resistance, and gave a current of 2 milliampères (·002 ampère). The electromotive force of the battery was therefore $E = RC = 1000 \times \cdot 002 = 2$ volts. The electromotive forces of batteries may be compared with great accuracy by *Latimer Clark's* Potentiometer.

This is well described in *Glazebrook and Shaw's* "Practical Physics."

133. **Voltameters.**—The periodical testing of a galvanometer is best carried out by means of a voltameter (§ 60). A battery of three or four cells, preferably of the *Bunsen* or *Grove* type, is connected up with an adjustable resistance, a voltameter, and the galvanometer to be tested. By a trial experiment it is found what resistance it is necessary to insert that the current may give a convenient deflection. It should be so arranged that the deflection of the galvanometer is 45°. Then everything is made ready and the current is turned on and the time taken; readings of the galvanometer are taken frequently when convenient, say at every thirty seconds, and the current is kept as nearly as possible constant by varying the resistance in the circuit. The current is allowed to pass for a measured time, conveniently ten minutes, and the circuit is then broken.

From the quantity of decomposition that has taken place in the voltameter, the total quantity of electricity in coulombs that has passed is known. This divided by the number of seconds gives the average current in ampères, the mean of the readings of the galvanometer is then taken, and this gives the average current indicated by the galvanometer which should be equal to that deduced from the voltameter. If it is not so, the necessary correction to apply to the galvanometer readings is easily calculated. The commonest form of voltameter sold by instrument makers is the water voltameter.

134. **Water voltameter.**—This instrument is shown in fig. 67. P is the stand with binding screws, B, B, T a glass tube, closed above by a perforated cork *b*. C

an inner tube, with platinum electrodes F, F′, and with two small openings, O, O′, for the exit of water displaced from the inner tube by the gases liberated. The inner tube is closed above by a stopper which can be moved by the wire A, passing through the cork *b*. The inner tube is to be filled with acidulated water and

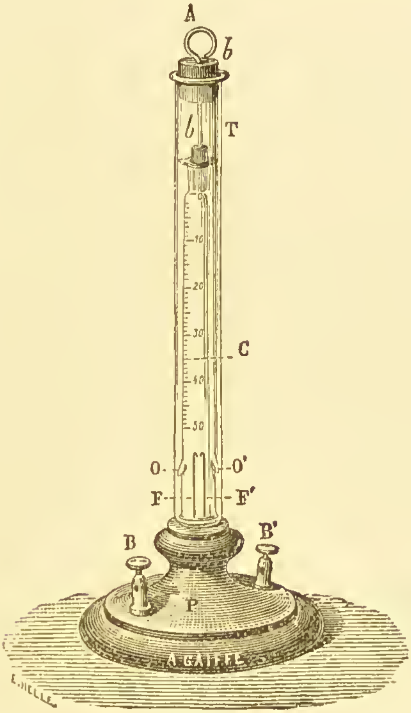

FIG. 67.—Water voltameter.

closed above, the outer tube is to be partly filled; the liberated gas collects in the inner tube and the water displaced is driven into the outer tube. The amount of gas liberated in a measured time can be read off by the graduated scale on the inner tube.

Though an exceedingly inaccurate instrument it is not difficul to use to check the readings of a galvanometer or ammeter. It may be used as follows:—Connect up with a battery giving sufficient electromotive force the voltameter, the galvanometer to be tested, and a resistance which must be adjustable, and of such a magnitude that the deflection of the galvanometer is a convenient one, viz., about 45° of arc. Take the time at which the current is started and record the reading of the galvanometer as described above. After ten minutes or a quarter of an hour, during which time the current has been kept as nearly constant as possible by varying the adjustable resistance, the circuit is broken and the volume of gas is read off, care being taken that the level of the water inside and outside the measuring tube is the same. The temperature and the height of the barometer must then be taken, all proper corrections being applied. The mean current recorded by the average reading of the galvanometer should then be equal to that calculated from the voltameter. This calculation may be carried out as follows:—Each coulomb of electricity (one ampère for one second) in passing through the water liberates ·118 cubic centimetres of hydrogen, and ·058 cubic centimetres of oxygen, or ·176 cubic centimetres of mixed gases; therefore in one minute ·176 × 60 = 10·56 cubic centimetres would be liberated by a current of one ampère, and in ten minutes 105·6 cubic centimetres. In the same time a current of ten milliampères would liberate 1·056 cubic centimetres of mixed gases.

As has been said the method is a most inaccurate one since a proportion of the gas which should be evolved always remains dissolved in the liquid or adherent to the electrodes. The corrections, too, are somewhat troublesome, though the method is so rough that they may often be omitted without much impairing the accuracy of the result.

135. **Copper voltameter.**—A far better form is the copper voltameter which is easily made up by anyone. It simply consists of two plates of thin copper sheet, say 10 centimetres by 5 centimetres, suspended in a beaker full of solution of copper sulphate. They can be clamped by binding screws to strips of wood resting across the top of the beaker. The plates are dried and cleaned carefully and weighed separately before the experiment is commenced. After it is finished they are

well rinsed in distilled water and again dried by gentle warming and weighed. That connected with the zinc pole of the battery will be found to have increased in weight, the other will have diminished by about an equal amount. The mean may be taken as the amount of decomposition. Now the electro-chemical equivalent of copper (the quantity deposited by one ampère in one second) may be taken as ·00033 grammes. Hence if the current flows for ten minutes and we find ·01 gramme of copper deposited, the mean current will be given by $C \times {\cdot}00033 \times 60 \times 10 = {\cdot}01$, or $C = {\cdot}0505$ ampères = 50·5 milliampères. Care must be taken that the density of current in the voltameter is not too great or the copper is apt to deposit in a flaky manner and scale off while being washed.

The copper voltameter is in many respects superior to the water voltameter since no special instrument is needed and an observation to determine the weight of the copper is much simpler than the determination of the volume of the gases evolved with all the necessary corrections for pressure and temperature. Besides in the latter case the observed result is incorrect, because the water always retains a portion of the evolved gas in solution.

CHAPTER VII.

PHYSIOLOGY.

General considerations. Diffusion of current in the body. The body as a conductor. The resistance of the body. Physiological effects of electrical currents. Electrical phenomena of nerve and muscle. Electrotonus. Pflüger's law of contraction. The law of contraction in the human subject. Unipolar excitation. Electrical reactions of muscle. The heart. Treatment of suspended animation. Sensory nerves. Nerves of special sense. Other organs. Refreshing action of the current Trophic effects. Electrical osmosis. Thermal effects. Electrical organs.

136. **General considerations.**—Although a large amount of work has been done on the electrical phenomena of nerve and muscle, yet the influence of electricity upon the tissues of the body is still very obscure, especially is this the case in its mode of action in the relief of disease. The condition of electrotonus (§ 142) is largely made use of to explain the therapeutic effects of electrical treatment in paralysis and other nervous disorders, but we have reason to believe that there is something more than this; many observers have thought that the applications of electricity to medicine are of use chiefly for diagnostic purposes, or as a means of exercising paralysed muscles, but there is no doubt that its uses extend much further, and that distinct changes, which may be called trophic changes, do follow treatment by galvanism; for instance, the treatment of uterine fibroids by Apostoli's method, where powerful currents are passed through the uterus, one electrode

being placed on the abdomen and the other introduced into the cavity of the uterus, certainly leads to diminution in the size of the tumour and to relief of the symptoms. It has also been observed that considerable increase in the subcutaneous abdominal fat has followed this treatment. The benefits of Apostoli's treatment have been spoken of as due to electrolysis, but until further help can be obtained from the physicists, who at present are able to tell us little about the state of affairs going on in an electrolyte, we must be content to remain uncertain whether this is the case or not.

There is no doubt, however, that in the liquid between the poles of an electrolytic cell there must be molecular changes quite as active, although not visible to the eye, as those other changes which we can see to be taking place in the immediate neighbourhood of the poles of the cell. The tissues of the body conduct the galvanic current in an electrolytic (§§ 58, 59) manner, and it is very probable that the tissue elements between the poles do share actively in the molecular changes which are set up.

137. **Diffusion of current in the body.**—The density of the current (§§ 68, 124) and the diffusion of the current as it passes through the tissues from one electrode to the other, have an important influence upon the results produced. It has already been stated that in large and heterogeneous conductors, like the human body, the current spreads out in sheets as it passes from anode to cathode. *Dr. De Watteville* has very clearly illustrated this as follows :—He says : "The reader may picture to himself the electrical density at any point of a circuit of variable diameter by representing the strength of a given current flowing through it by a certain number of lines. These lines expand in the wider

portions of the circuit owing to the diffusion, and become crowded together in the narrower parts. A crowd issuing through a narrow door, and through gradually expanding passages, and finally reaching the street, like electricity flowing through a circuit of variable diameter, is said to be densest at the narrow exit, and it thins out, is diluted in space as it were, as it reaches the wider outlets."

The path of a current between two electrodes placed upon the body surface is not to be marked out simply by drawing direct lines from the one to the other, for the whole of the conducting tissues between the electrodes help to provide a passage for the current, which spreads out from beneath the positive electrode, becoming less and less dense as it occupies a wider and wider sectional area of the conductor, and again grows denser as its lines of passage become once more gathered together to reach the negative electrode.

Fig. 69 shows the divergence of the directions of these lines of current as they pass from a positive electrode placed upon the back of the arm to reach the negative electrode placed somewhere upon the trunk, and it very well illustrates the fact that the current is not confined to the space directly between the electrodes, for some of the lines which indicate its direction, actually commence their course by curving downwards through the tissues below the electrode; once more using *Dr. De Watteville's* simile of a crowd, we might compare this to people in the streets of a busy city, with a few of the individuals choosing to go by a circuitous route through side streets in order to secure a more open, even if a more roundabout passage.

It follows that parts of the body which are outside the direct line of the electrodes may be influenced by the current passing between the electrodes, and it will be seen from the chapters on treatment that this may sometimes be advantageous, and sometimes the reverse.

It also follows that the size of the electrodes is of importance in treatment, for at the surface of contact of a small electrode the density of current per unit of surface, when a definite quantity of current is flowing, will be greater than when large electrodes are used; this point has been already alluded to in § 124, and will be again referred to later.

138. **The body as a conductor.**—The body is a conductor exactly in the same way as saline solutions or moist sponges are conductors, that is to say, it is an electrolyte, and the tissues between the electrodes during the passage of a current are in exactly the condition of the liquids in an electrolytic cell, consequently the passage of the current causes the accumulation at the positive electrode of acids, chiefly hydrochloric, from the abundance of sodium chloride in the juices of the body, and of bases, chiefly soda for the same reason, at the negative electrode. The region between the poles shows no evidences of either free acid or free alkali, and yet we feel sure that there must be some exchanges taking place all through the chains of molecules between anode and kathode. Moreover, it is not reasonable to assume that the changes are only taking place in the fluids of the intercellular spaces, for they must also go on in the whole of the cell substance which is traversed by the current.

139. **The resistance of the body.**—The conducting power of the tissues, like that of any other conductor, depends upon their sectional area, and upon the length of tissue to be traversed.

Dr. W. H. Stone, "Lumleian Lectures," 1886, has carefully considered the subject of the resistance of the human body, and finally sets it down at about 1000 ohms. But unless great care be taken to ensure good contacts the resistance will be much higher than this, because the greater part of the resistance of the body is situated in the skin. We are told that *Count du Moncel* experimentally determined the electrical resistance of his wife from wrist to wrist, using small platinum electrodes, and found it at first to be 3,500 ohms, gradually falling to 2,200 ohms; the diminution in resistance was caused by the electrolysis and destruction of the skin beneath the electrodes leaving scars upon the Countess' wrists for the rest of her life. According to *Dr. Stone* the human body, from an electrical point of view, is a mass of fairly well conducting material, enclosed in a remarkably badly conducting cutaneous envelope. "In measuring resistance, therefore, it is necesary first to eliminate surface contact resistances, for the resistance at the skin may be 8,000 to 20,000 ohms, but the real and essential point to be ascertained is the very much smaller resistance of the deeper tissues. To obtain good electrical contact it is necessary that the poles should be very large as compared with the current, and in practice this condition can be fulfilled by immersing the feet or hands in baths of brine in contact with an electrode of lead having a surface of from 50 to 100 square inches. In this way the resistance of the skin can be reduced to zero, so that it is a contact superior to that given by the introduction of silver needles three inches deep into the tissues; readings of the resistance of the body under these conditions gave from foot to hand, 1027, 1032 and 1320 ohms respectively in three cases, and in the same three patients the resistance measured from foot to foot was 930, 930 and 945 ohms." It appears from these experiments that the essential resistance of the full length of the body from hand to foot is about 1000 ohms, but that from the resistance of the skin a much higher figure, 3000 or 5000 ohms or even more, may be reached. With needles inserted into the skin, as in electrolysis of nævi, the resistance is much less; for the length of tissue to be traversed is less, particularly so when both poles are inserted into the nævus, and are consequently close together. After the current has been running for a short time the resistance begins to rise from the development of polarization (§ 100) in the tissues, this rise of resistance is not usually perceptible when ordinary medical electrodes are used, because it is more than masked by the improvement in conducting power which takes place after the current has been flowing long enough to increase the vascularity of that part of the skin which is in contact with the poles.

In the experiment of *Count du Moncel* on his wife the resistance fell rapidly as the skin beneath the electrodes became first congested and later destroyed, but even then the reading was higher than those of *Dr. Stone*, because considerable polarization had been produced and that raised the resistance of the body, or more correctly, perhaps, it produced an opposing electromotive force which simulated increased resistance.

Dr. Stone has also found that in six cases of hemiplegia which he tested, the paralysed side offered much less resistance than the sound side; the difference between the two sides being on the average 400 ohms. The resistance of the body has also been shown to be greatly diminished in exophthalmic goitre; probably this is due to the increased moisture of the skin in this disease.

In electrical treatment the resistance of the body must usually be taken as the sum of the resistances of the skin, and of the deeper tissues, because the requirements of localised treatment often make it impossible to use the large lead electrodes and brine baths which were employed by *Dr. Stone*. The total resistance of the human body will be found to vary tremendously with the variations in the thickness or the dryness of the skin, also, according to *Erb*, it varies with the number of sweat ducts, hair follicles and sebaceous glands in any part, for it is largely by means of these fine channels that the current passes, accordingly in different persons the resistance between any symmetrical points may vary very widely, and in the same person, different regions of the skin may offer very different resistances. When the current is applied to a mucous membrane the resistance is much lower; and when it is applied through the medium of needles thrust into the tissues, the resistance may be as low as 100 ohms or less, according to the distance between the poles; for instance with both poles in a nævus a current of 100 milliampères can be obtained with ten volts showing the resistance to be less than 100 ohms, and with both poles introduced into the sac of an aneurism a resistance as low as 10 ohms has been registered. So, too, it is a well known observation that the resistance diminishes with the duration of the current, the size of the electrodes and the number of cells remaining constant. *Erb* gives a table which brings out this point clearly, the experiment was commenced with eight cells, and the readings of a galvanometer in circuit were noted; the number of cells was progressively increased by fours, and at every step the current was made and reversed several times, after the number of cells had been raised to 24 it was lowered again in the same manner until at the end of the experiment, when the number of cells left in circuit was only four, they were actually giving a greater deflection of the galvanometer than twelve cells had previously done.

Commencement:—

With 8 cells	0° defl.	With 20 cells	46° defl.
,, 12 ,,	6° ,,	,, 16 ,,	40° ,,
,, 16 ,,	28° ,,	,, 12 ,,	34° ,,
,, 20 ,,	42° ,,	,, 8 ,,	26° ,,
,, 24 ,,	50° ,,	,, 4 ,,	12° ,,

The results given in this table would probably have been much less marked if there had first been a prolonged sponging or soaking of the skin with hot water at the points of application; for the effects shown depend at least in part upon the increased vascularity and perspiration which the galvanic current produces, and which could have been almost equally well produced by the stimulating effect of hot water.

The excessive resistance which is sometimes offered by the thick dry skin (especially of patients who have been long confined in bed, and when there has been little or no perspiration for some time) sometimes presents a considerable obstacle to the electrical examination of their muscles, and unless care is taken, it is apt to mislead.

140. **Physiological effects of the current.**—The effect of electrification upon the nervous system seems to depend partly upon the quantity of current flowing, and partly upon the rate of change of the electromotive force in the circuit. It is possible to tolerate the gradual introduction or the steady passage of twenty or thirty milliampères through the body if the contacts with the skin at the electrodes are large and good, but the sensa-

tion of shock is severe, if currents of five milliampères are rapidly thrown into the body; and when the current is broken rapidly its sudden cessation also produces a far greater impression than that felt while it is running steadily. This shock at the break or opening of the circuit is difficult of explanation, and nothing comparable to it is observed with inanimate electrical circuits or apparatus, for it is not of the nature of an induction effect; the explanation which is offered in physiological textbooks, namely, that a sudden fall of potential is an effective stimulus to a nerve fibre is after all no explanation.

The important part played by rate of change of a current in producing physiological effects is clearly shown by what has just been said of the current slowly or suddenly made and broken through a circuit which includes the body; the part played by the quantity of current passing is seen by a comparison of the effects of a spark drawn from the prime conductor of an electrical machine with that from a Leyden jar. A spark a quarter of an inch long taken from the former produces only a slight impression, but a spark of the same length from the jar gives a violent shock. The difference between the two is largely a difference in quantity of current passing. In both cases the electromotive force is very high, and the total quantity is small; but, in the case of the Leyden jar there is, for the extremely brief instant of the discharge, a fairly large current, because of its capacity (§ 32) as a condenser.

141. **Electrical phenomena of nerve and muscle.**—The electrical phenomena of nerve are as follows:—

Nerve acts as a conductor; its resistance being about equal to that of saline solutions. This is the case whether it be alive or dead, but there is a peculiarity in its conductivity which is unlike that of saline solution, viz., its resistance in any direction does not depend solely upon its sectional area as would be the case in homogeneous conductors, but it conducts more readily along the length of its fibres than across them, and the same peculiarity is also found in muscle.* *Brenner* has shown that in nerve the transverse resistance is as 5 : 1, and in muscle as 9 : 1, as compared with their longitudinal resistances. It is probable that these differences in resistance simply signify that as conductors they are not homogeneous.

Electrical currents in nerve and muscle.

a. Current of rest.—A living nerve or muscle is a source of electrical currents, for if the wires of a sensitive galvanometer be attached to two points in a removed portion of either, the existence of a current will be made manifest by the deflection of the galvanometer needle, its direction being that which indicates a current passing through the wire from the central part of the length of nerve to its extremities; this current is called the *current of rest.* It is more easily demonstrated in an excised and therefore damaged portion of nerve or muscle than in a part which is still lying uncut in the body; and indeed it is probable that this current of rest only exists in damaged tissue, and is not present in normal parts at all, but that it is set up by chemical changes resulting from the injury.

b. Current of action.—If while the galvanometer is attached to it, the nerve or muscle be stimulated in any way, whether by electrical, mechanical, chemical, thermal, or any other means, then the galvanometer needle will give evidence of the production of an electrical current by a momentary deflection in the opposite direction to that produced by the current of rest; this has been called the *negative variation* of the current, or the *current of action*. It is propagated in both directions from the point stimulated, and travels in nerve at the rate of 28 metres per second, that is to say, the disturbance of equilibrium producing the current moves at that speed, which is very much slower than the rate at which an electrical current travels along a nerve, and is an entirely different thing. The impulse which passes along a nerve to cause muscular contractions or sensory impressions is not an electrical impulse pure and simple, although there is an electrical change associated with it. If a nervous impulse was simply an electrical current it should be transmissible by an electrical conductor, as for instance a copper wire, but it is not so transmitted, neither will a piece of damaged nerve convey a nervous impulse, although it may readily convey an electrical current, moreover, the velocity of an electrical current in a conductor such as a nerve trunk is immensely more rapid than the velocity of a nervous impulse in a nerve trunk. In muscle the current of action is propagated at the rate of three metres per second.

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* This may well be compared with the phenomena of the conduction of heat in wood, which takes place at a different rate according to the direction of the grain of the wood.

c. Electrotonic current.—During the passage of a constant current through a length of nerve a change is produced in its currents of rest. Take the case of a long portion of excised nerve which has electrodes arranged for the passage of a constant current along its middle third from r to r', and has also two galvanometers each including in their circuit a short length of nerve near its extremities, and arranged to show the existence of the currents of rest; when the constant current, sometimes called the *polarizing current*, has been thrown into the nerve, and the momentary negative variations produced at the moment of closure are over, the deflections of the galvanometers will be found altered, the alteration depending upon the direction of the constant current. One of them will exhibit a greater deflection than before, the other one will exhibit a lesser deflection, as though the polarising current were reinforcing the one and antagonising the other.

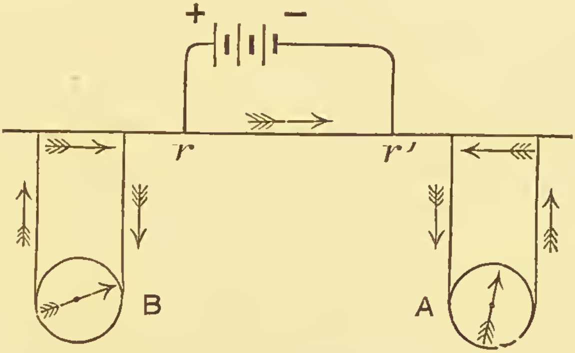

FIG. 68.—Electrotonic currents.

A reference to the diagram (fig. 68) shows that the constant current has the same direction as the current of rest in the circuit of the galvanometer B, and has a direction opposite to the current of rest in the circuit of the galvanometer A, and accordingly the deflection of the galvanometer B is increased as if reinforced, and that of the galvanometer A is diminished as if antagonised.

142. **Electrotonus.**—The electrotonic currents just described are not the only effects which are produced in a nerve during the passage of a constant current along it, for there are produced in addition certain alterations in the irritability of the nerve and certain alterations in

its conductivity ; this altered state is known under the name of *electrotonus*. Electrotonus then is the condition of a nerve during the passage through it of a constant current, but the effects in that part of the nerve near the anode are not the same as those near the kathode, thus there is one altered state round the anode or *anelectrotonus* and another different altered state round the kathode or *kathelectrotonus*.

a. Anelectrotonus.—In the region of the anode the *irritability* of the nerve is diminished, the fall in irritability taking place at the moment when the circuit is closed, and remaining diminished till the circuit is again opened, when there is a return to the normal. Also the *conductivity* of the nerve for nervous impulses becomes diminished by the development round the anode of a resisting area through which nerve impulses pass only with difficulty.

b. Kathelectrotonus.—Round the kathode the closure of the circuit causes a *rise of irritability* which is maintained during the passage of the current, and returns to the normal level when the current has ceased to flow. The sudden rise of irritability at the kathode on closure is a stimulus to the nerve, and so also in a less degree is the rise from a diminished irritability to the normal at the anode on opening. The importance of electrotonus partly lies in the explanation which it affords us of the behaviour of muscle towards constant currents, at their make (closure) and break (opening). Electrotonus is also useful medically in giving us a clue to the treatment of disease, accordingly where it is wished to increase the irritability of a part the condition of kathelectrotonus should be set up by applications of the kathode, and conversely the application of the anode is to be preferred for inducing a state of diminished excitability and so of relieving pain and spasm. It is generally known that the constant current causes a muscular contraction at the moment when it passes into a motor nerve, and again at the moment when it is shut off, but that during its steady passage the muscle is not thrown into contraction ; this is true for the most part but does not hold good for weak currents, nor for very strong currents, which may produce a contraction at the make only, or at the break only, or may produce a state of tetanus. It can be easily demonstrated by crushing the nerve at one part that stimuli above the damaged point cannot transmit a nervous impulse downwards to the muscle, for by the injury the nerve is disabled from conveying an impulse, though remaining an electrical conductor. If then the electrodes be placed upon the nerve, one above the point of injury and one below it, it will be observed that the contraction will occur at closure only when the pole below the crushed part is the kathode, and at opening only when the pole below the crushed part is the anode, showing that a stimulus is developed at the kathode at the moment of rise of irritability at closure, and that the contraction at break is started from the anode at the moment of rise from a minus degree to zero (opening). Further the kathodal closing contraction is a stronger one than the anodal opening one, the rise of irritability from the normal degree having a greater effect than the anodal rise to normal, and the effect of the anodal opening stimulus is further diminished because of the anelectrotonic zone of impaired nervous conductivity which surrounds the anode and blocks the passage of the nervous impulse downwards to the muscle.

143. **Pfluger's law of contraction.**—This name is given to a table which sums up the results of ex-

periments with weak, medium, and strong currents in such a way as to show the effect of opening and closing with (*a*) descending currents (kathode nearest to muscle) and (*b*) ascending currents (anode nearest to muscle); *c* stands for contraction.

Descending.			Ascending.	
Current.	Closure.	Opening.	Closure.	Opening.
1. Weak.	*c*	—	*c*	—
2. Medium.	*c*	*c*	*c*	*c*
3. Strong.	*c*	—	—	*c*

The non-appearance of an opening contraction with weak currents is explained by saying that the kathodal stimulus at closure is more powerful than the anodal stimulus at opening, consequently, if the experiment be commenced with a current of medium strength, producing contractions at closure and at opening, and if the current be gradually and progressively weakened till it approaches the point of minimal stimulation, the weaker anodal opening stimulus will be the first to fail, and it will have become too weak to cause a contraction before the stronger kathodal closure stimulus has become too weak. If the current be still further reduced a point will be reached when neither closure nor opening will have any effect upon the muscle. With weak currents then, the closing contraction is the first to appear, the opening contraction requiring a stronger current for its production, or in other words, with an uniform and moderate current, the closing contraction is stronger than the opening contraction.

If the current is increased very much in strength a point is reached when the contraction is no longer produced at both closing and opening; and instead it shows itself either only with closure if the current be descending, or only at opening if the current be ascending. The reason of this is that with strong currents there is a considerable obstacle offered to the passage of nervous impulses by the area of anelectrotonic nerve, and this lying chiefly between anode and kathode, is able to block the passage of the impulse of opening from the anode to the muscle if the current be a descending one, and of the closing impulse from the kathode if the current be an ascending one. Currents sufficiently strong to show these effects are not used in medical treatment, and it is not necessary to dwell longer upon them, but the other phenomena of the law of contraction which are of importance in practice are that with the weak or moderate currents used in medicine, the closing contraction appears before the opening contraction, and when they are both produced the former is the more vigorous of the two. Further the contraction is best seen with a descending current for then the kathode is nearest to the muscle and is able to transmit its impulse to the muscle without any interference from the diminished conductivity which is set up round the anode. When the current is ascending and the kathode is the furthest away from the muscle it is separated from it by the resisting anodal region, consequently the ascending closing contraction is weakened, and produces an effect about equal to that of the ascending opening contraction.

These effects studied in the first instance in dissected and exposed nerves of the lower animals, can also be demonstrated in the human subject, and their value and significance will be brought out when the subject of diagnosis is being treated. It will then be shown that in certain pathological conditions the normal reactions are so altered that the anodal closing contraction may be equal to or greater than the kathodal closing contraction.

144. **The phenomena of contraction in the human subject.**—*Erb* has shown that the condition of affairs is not quite so simple when a nerve is being tested *in situ*, as it is when the nerve has been exposed, and has the electrodes directly in contact with it. In speaking of the electrical examination of living muscles through the skin he says: "We have to deal with nerves which are surrounded with more or less thick layers of well conducting tissues, and which are permeated by a large number of the threads of current diffusion, we cannot therefore possibly maintain any uniform current density in the nerve; the greatest density of the current will always be found immediately beneath the electrodes; even in the intrapolar portions of the nerves the density will soon become so slight, if the electrodes are not closely approximated, that a part of the nerve may be regarded as not traversed by the current." "In the neighbourhood of each pole there occur two tracts permeated by an ascending and by a descending current respectively. Thus it is impossible to institute a strictly physiological experimentation on the living man, more especially the direction of the current which has erroneously been considered of so great importance must be excluded from all account, and we must strive to find the law of contractions of the living motor nerve within the body without reference to it."*

The order of appearance and the relative strength of the contractions so produced have been tabulated as follows :—

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* *Von Ziemssen's* "Handbook of General Therapeutics," vol. vi., "Electrotherapeutics," translated by *De Watteville*.

a. Kathodal closing contraction (KCC) = 4.
b. Anodal ,, ,, (ACC) = 2.
c. Anodal opening contraction (AOC) = 2.
d. Kathodal ,, ,, (KOC) = 1.

145. **Unipolar excitation.**—By this means an explanation is given of the law of contraction as observed in the living subject, for it is evident that in the common case of the anode placed on some indifferent part, such as the sternum, and the kathode upon the muscle to be tested, which we will suppose to be the *gastrocnemius*, one would expect (supposing it to be true that the stimulus of closure is purely kathodal and the stimulus of opening is purely at anode), that the act of closing the circuit would give a contraction KCC in the *gastrocnemius*, but that the opening would only give a contraction in the muscles near the sternum. Then there would be no KOC in the gastrocnemius, and again in the same way with kathode at sternum and anode on gastrocnemius, there would be no ACC in the muscle, but only an AOC. Observation shows that with the unipolar method one can nevertheless obtain all four effects, KCC, ACC, AOC, KOC, in a muscle ; and the explanation offered is that round the pole (actual pole) there are areas of opposite sign (the virtual pole). Where the threads of current in their passage through the limb enter into the nerve from the anode there is an anodal area, and where they emerge from the nerve or muscle there is a kathodal area. *Erb* has carefully cleared up this point by the diagram and following statement (fig. 69).

"A glance at the figure will show that an isolated pole placed upon a nerve must have not alone one, but even two virtual opposite poles in its neighbourhood; if the current enters through the anode in a certain density the threads of current will flow along both directions of the nerve with diminishing density, the kathode may be regarded as virtually present at the point at which the density has become so slight that the current is ineffective. Every anode is therefore surrounded by two kathodes of much less density; and the reverse also occurs round the kathode; under all circumstances, in the unipolar methods of application, in addition to the action of the pole applied directly we must therefore expect to find the action of the opposite pole though very much enfeebled."

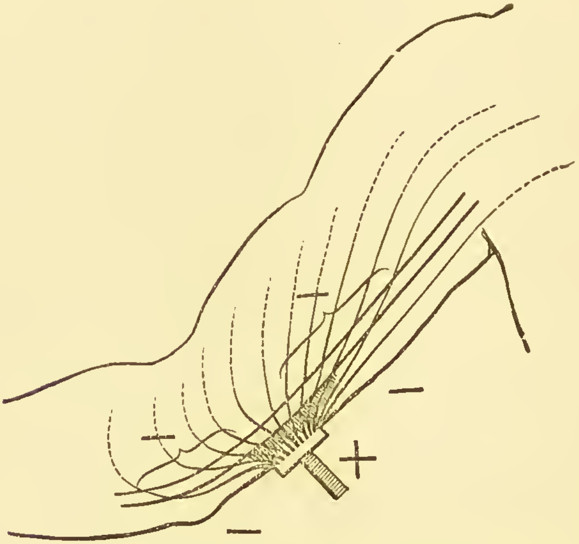

FIG. 69.—Lines of current diffusion round an electrode.

146. **Reactions of muscle.**—*a. Skeletal muscle.*—In a normal muscle the effect of direct stimulation of its fibres is concealed by the effect produced upon it through its nerves, for the intramuscular branches of its nerve both receive the impression better, and transmit

it to all parts of the muscle more rapidly than the muscle fibres could do it by themselves if no nerves were present. Still muscle *per se* is irritable and capable of responding to stimuli by a contraction ; but for this it is necessary that the stimulus should have a certain minimum duration, rather longer than the minimum for a nerve trunk, accordingly it often happens that a muscle whose nerves have undergone injury may not respond to the rapid stimuli of induction currents, while they will still respond to the constant current slowly interrupted.

We have already alluded to the occasional production of tetanus by the constant current, this is usually noticed as a phenomenon continuing on the KCC when strong currents are employed, and it is observed both when the stimulus is applied to the nerve and when it is applied to the muscles ; it is sometimes expressed by the symbol KCT (kathodal closure tetanus), or by KDC (kathodal duration contraction).

b. Unstriped muscle.—The behaviour of unstriped muscle resembles that of striated muscle, except in so far as the latent period of unstriped muscle is longer, and the rate of passage of the contraction from the neighbourhood of the point stimulated is slower, in consequence of this it is quite easy to see that the stimulus starts from the kathode at closure, and from the anode at opening. When an organ containing unstriped muscle is stimulated by a succession of faradic shocks, it slowly and gradually passes into a state of tonic contraction which persists for some time after the stimulation has ceased ; faradism has been applied to certain of the abdominal viscera for the purpose of setting up contractions in their unstriped muscle and improving the tone of the organs.

c. Heart muscle.—The effect of electrical stimulation on heart muscle is peculiar just in so far as the habits of heart muscle are so; thus heart muscle has a general correspondence to unstriped muscle but it has a more highly developed tendency to rhythmic contraction than that which can be seen in unstriped muscle and a greater degree of activity, shown by its quicker movement and its shorter latent period; it has also the peculiarity that a minimal stimulus is as effective as a maximal, consequently gentle electrical stimulation tends chiefly to alter the rate of the rhythm of the heart and by a suitable series of shocks in regular sequence the heart can be caused to take up the rate of the series of shocks, and so can be quickened or slowed (the latter being more difficult).

What is known as the refractory period of heart muscle depends upon the tenacity with which it maintains a rhythm which it has once acquired, and the same rhythmic tendency makes it almost impossible to produce a state of true tetanic contraction in it. It is more easy to influence the heart by the continuous current with regular interruptions or reversals than by the induction apparatus.

147. **Electricity in cases of suspended animation.**—Great uncertainty exists as to the mode of using electricity in cases of apparent death by drowning, from the administration of chloroform, or from poisoning by carbonic acid gas. Electricity in these cases is not of much use for the purpose of influencing the heart, but is valuable for assisting the process of artificial respiration. The region of the heart should be avoided as much as possible. Anything which upsets the rhythmical contraction of the heart is likely to arrest its action altogether. It has been found by experiment upon the

heart of dogs, that if the application of the faradic current can be timed so as to be synchronous with the normal contractions of the organ, a contraction of increased strength is induced, but if not so timed the ordinary rhythmical action is interfered with, violent tremors of the cardiac walls occur for three or four minutes (as if the heart were endeavouring to recover its lost rhythm) then weaker tremblings follow and ultimately all movement ceases. In cases of apparent death, if the heart is still beating at all, its action is very feeble and therefore more likely to suffer from an injudicious application of electricity. In these cases, therefore, it is recommended that electricity be used rather as a help in restoring respiration and for this purpose it is best that the operator should stand on the right side of the patient and as the arms are raised each time in the performance of *Sylvester's* method of inducing artificial respiration, one pole of a faradic apparatus should be applied to the motor point of the phrenic nerve on the right side of the neck (or a divided electrode can be used, and applied to both sides) on the outer edge of the lower part of the sterno-mastoid, and the other pole to the right sixth intercostal space at a level with the ensiform cartilage, or to the lower part of the sternum; the current should run for two seconds, and be suspended for two seconds alternately. Contractions of the diaphragm will thus be induced at the same time that the thoracic cavity is enlarged by the raising of the arms and a larger amount of air will enter the chest. The application of electricity in these cases of apparent death should always be secondary to the endeavours to produce artificial respiration by other means. Time is of the greatest importance and the patient should not be left while an electric battery is being sought for or set to work, these duties should always be left to a third or fourth person whose assistance is not actually necessary for carrying out the ordinary movements for inducing artificial respiration. If electricity is employed it should be the faradic or interrupted current, and the most useful because the most ready apparatus is the old-fashioned magneto-machine, which is set in action by turning a handle.

148. **Sensory nerves.**—Just as the electrical stimulation of motor nerves causes muscular contractions, so the stimulation of sensory nerves produces sensations. Accordingly, when an ordinary mixed nerve trunk is stimulated, its motor fibres make the muscles supplied by it contract, and its sensory fibres convey to the brain of the patient experimented upon a peculiar sensation or *shock*, strong or weak, in proportion as the current is strong or weak. The peculiarity of the sensation also produces a mental effect, so that different patients appear to vary in their susceptibility to these sensations, thus it is said that if a current be transmitted from hand to hand through a line of people, some will say they felt the shock severely, and some only slightly. In the case of *Muschenbroek*, the inventor of the Leyden jar, the novelty and peculiarity of the shock that he received at his first trial of it produced such an effect upon him as to take away his breath and make him ill for two days.

The sensation produced when the sensory nerves are stimulated is called a shock, and according to the mode of application, they may be known as galvanic, faradic, or induction shocks, and shocks from a statical machine or Leyden jar.

a. Galvanic sensations.—In the case of the constant galvanic current, there is a sensation not only at closure and opening, but also during its steady passage, if the current be fairly strong, but not if it be weak.

The sensations are more perceptible at the kathode than at the anode, but a good deal depends upon the relative sizes of the electrodes ; if one be much smaller than the other, then the greater density of current at the smaller one increases the cutaneous sensations there. If the electrodes be held still in one place, other sensations of a burning character are felt and are accompanied by reddening, urticaria, or blistering of the surface, these changes and the burning pain are usually ascribed to the formation of products of electrolysis. In the removal of hairs by electrolysis, the fine needle-like electrode introduced into the hair follicle, feels much as though it were very hot. The nature of the surface of the electrode also modifies the sensation ; and the current is less painful when the electrodes are firmly pressed upon the surface, because the contact is then better and the current is distributed over more points of entrance.

b. Faradic sensations.—The faradic apparatus gives a series of shocks corresponding to the rapidity of the vibrating contact breaker, and if they be applied to the dry skin the sensation is more sharp and pricking than when the skin is well moistened. On this account it is usual, when the sensory effect is especially desired, to employ a dry brush of many fine metallic wires for the electrode.

The faradic shocks are also more painful if the electrodes are applied to surfaces far apart from one another, because of the much greater length of sensory nerves which are influenced in that case ; when convenient it is better to limit the application to the affected parts, and so to spare needless discomfort to the patient.

149. **Nerves of special sense.**—The nerves of special sense respond to electrical stimulation by their own special sensations, thus stimulation of the olfactory nerve produces a smell "like phosphorus," and stimulation of the optic nerve produces the impression of a flash of light. The optic nerve seems to be remarkably sensitive to small electrical currents, and the sensation of a flash of light is very easily produced by the small current obtained from a silver coin and piece of zinc put into the mouth, between the gums and cheek. When the metals are made to touch, the optical effect is distinct. Some observers have even thought that the colour of the flash seemed to depend upon the direction of the current, and that the kathodal closure gave a reddish colour and anodal closure a bluish one. These effects can be fully studied by a battery of four or five elements, with one pole at the nape of the neck and the other over the temple or eyelids. Experimenters must, however, remember the accident which befell Duchenne, who applied a current of unknown strength to a patient's face, and apparently caused very serious damage to the sight of one of his patient's eyes.

The auditory nerve.—This nerve also can be made to respond to galvanic stimulation. It is not so very easy in healthy individuals to produce the electrical reactions of the auditory nerve, for fairly strong currents are required, and some of the effects upon the eyes and brain make the experiment unpleasant; but the investigation is important, because one is frequently called upon to treat *tinnitus aurium* by the galvanic current, and the prognosis in any particular case turns largely upon the way in which the auditory nerve reacts. There is a close likeness between the formula of the auditory nerve and that of the other nerves. The kathodal closure produces a sensation of sound, which continues during the passage of the current, but the anodal closure does not; on the other hand the anodal opening produces a sound and kathodal opening does not. The formula then is:—

KC sound.
KD sound.
KO —
AC —
AD —
AO weak sound.

These auditory phenomena will be again referred to in Chapter VIII.

Galvanic stimulation of the nerves of taste is easily produced, and the simple experiment just mentioned for producing the optical sensation of a flash of light will at the same time produce a metallic taste, and by passing a current from one pole at the back of the neck to the other below the chin over the hyoid bone, the same metallic taste is produced.

150. **Other organs.**—Besides the physiological action of electricity upon muscle and nerve, it has an action on secreting glands, upon certain viscera, and upon the brain. It is quite in accordance with what one would naturally expect that a current passing through a secreting gland or through its secretory nerves should cause increased secretion; and that a current passing through a viscus containing unstriped muscle should cause peristaltic contractions of that viscus: and there is no need for us to enter into detail at present by describing the particular behaviour of the uterus, of the bladder, of the intestine, or of the spleen, for these points will be better treated of later.

In the case of the brain experimental physiologists have made much use of electrical stimuli for determining the situation of motor centres in the exposed cerebral cortex. When a continuous current is passed transversely through the skull, with the electrodes on the temples or mastoid processes, there is a disturbance of equilibrium, a feeling of giddiness, or an actual unsteadiness, with a tendency to fall towards the side of the anode, and conjugate deviation of the eyes to the side of the kathode, with a kind of oscillation or lateral nystagmus.

It has been supposed that the disturbance of equilibrium depends upon a state of kathelectrotonus of one hemisphere with anelectrotonus of the other; the former hemisphere being in a state of exalted excitability and the latter in a state of diminished excitability, their action is no longer balanced, and a sensation of giddiness is the result.

The brain is not easily influenced by faradic currents applied to the outside of the skull, though responding readily when the electrodes are applied directly to its substance.

151. **The "refreshing action" of the galvanic current.**—*Dr. G. V. Poore*[*] has reported some remarkable experiments upon what has been called by *Heidenhein* "the refreshing action" of the constant current; he investigated the fatigue of muscles produced when a weight is held out steadily at arm's length, and gives the instance of a patient who was able to hold out his arm horizontally with a weight of seventeen ounces in the palm for a period of four minutes and then complained of great pain in the muscles and fatigue, and declared his inability to go on but was relieved of his pain at once by the passage of a con-

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[*] "Electricity in Medicine and Surgery," *Dr. G. V. Poore*, London, 1876.

stant current in a descending direction along the arm. Another person was then experimented on in the same way; after holding out the weight at arm's length for seventy seconds, he felt pain and fatigue, but the application of the current at once removed both, and he continued to support the weight for five minutes and a quarter, and at the end of that time was willing to go on longer. *Dr. Poore* says: "similar experiments to these have been tried on several of the author's friends and they all tend to show that the endurance of voluntary muscular action is enormously increased by the passage of a constant current, and the feeling of fatigue both during and after the prolonged effort is mitigated or entirely obviated."

Dr. Poore also demonstrated that the force as well as the endurance of a muscular effort could be increased by a galvanic current. Eight successive squeezes with a dynamometer at intervals of ten seconds gave an average of 48½ pounds for each squeeze, but eight more squeezes with the aid of the current gave an average of 59½ pounds, although they came ten minutes after the first series, and while there was distinct consciousness of fatigue from the first experiment.

The current used was never strong enough to produce involuntary contraction of the muscles.

152. **Trophic effects.**—Experiments were made by *Dr. Beard** to determine the effect of general faradization upon the growth of some puppies, they were kept under treatment for four weeks, being faradized daily; at the end of the time the two puppies which had been so treated had gained in weight faster and were perceptibly bigger than the two others, which had been kept untreated as control animals; however, other

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* *Beard and Rockwell*, "Medical and Surgical Uses of Electricity."

experiments gave conflicting results. It is reasonable to expect that the metabolism of muscle should be increased by the vigorous stimulation of faradism, and that a young animal should increase in size in consequence of the increased metabolism, just in the same way as massage of the muscles increases their size and activity.

153. **Electrical osmosis.**—The fact has been long known that a movement of electrolytic fluids comparable to osmosis takes place in the direction of flow of the current, namely, from the positive to the negative pole; and fluid can in this way be made to pass through membranes or porous diaphragms against the force of gravity; and it has been proposed to make use of this process for the introduction of drugs into the body through the skin. It is evident, however, that it is rather an elaborate method of administering a drug, and only in certain cases would it have any advantage over the methods of giving drugs by the mouth or hypodermically; besides, it would be difficult to know when the proper quantity had passed into the system. It was also hoped that in this way it would be possible to apply drugs locally, as for instance iodide of potassium to a gumma, but this cannot be satisfactorily effected because the drug is carried off by the circulation quite as fast as it enters through the skin. Still, there is one particular object which can be well and conveniently secured in this way, namely, the introduction of cocaine to produce local anæsthesia of a portion of the skin, this can be done very simply by covering the positive electrode with a thick pad of absorbent cotton well moistened with the cocaine solution, and holding it steadily to the part, which should be first well sponged with hot water; with five milliampères of cur-

rent the skin should become anæsthetic in about six or seven minutes.

Hollow cup-shaped electrodes covered in by membrane have been contrived to hold solutions for this local medication, and the terms *cataphoresis* and *cataphoric medication* have been applied to the process. *Erb* has suggested that it might prove useful for the introduction of drugs into diseased joints; using a pair of cupped electrodes, one on either side, and reversing the direction of the current at intervals of five minutes.

154. **Thermal effects.**—With the small currents used in medicine there is no appreciable heating of the tissues. In cases where death has been caused by the passage through the body of the powerful currents used for electric lighting, well marked signs of the production of heat have been observed *post-mortem*.

155. **Electrical organs.**—The electrical organs of many fishes (Electric Eel, Torpedo) may be briefly noticed in this chapter. They consist of lobes of a honeycomb-like structure, usually developing in a similar way to muscle, and supplied freely with nerves which terminate in the cells of the honeycomb in expansions something like those of muscle end-plates; irritation of their nerves causes an electrical discharge. It appears that they may have become specialised and developed from ordinary voluntary muscle, for the sake of utilising the electrical current of action, and that the structural changes are associated with the development of this portion of the muscular mechanism at the expense of its strictly motor powers. The chemical examination of the electrical organs seem to show that the products of their activity are very similar to those of active muscle, CO_2 and an acid reaction being produced.

Du Bois Reymond showed long since that muscular contraction always yields a current which can be measured by a galvanometer, and *Waller* has lately shown a method of demonstrating in the human subject that there is an electrical current produced by the heart's beat, and that it can be led off to a galvanometer by wires from the two hands. It may be that the peculiar powers of electric fishes have grown up from the electrical current of action common to all contracting muscle, but it is difficult to trace the intermediate steps in the scale of development. The skate has an electrical organ in its tail which is not able to give shocks, although it can strongly affect a galvanometer.

CHAPTER VIII.

DIAGNOSIS.

Method of procedure. Comparison of diseased and sound sides. Use of the galvanometer. The motor points. Relation of spinal nerve roots to muscles. Importance of experiments. Bilateral affections. Prof. Erb's method. Electro-diagnosis charts. Morbid changes in the electrical reactions. Quantitative changes. The reaction of degeneration. Course of the reaction of degeneration. Partial reaction of degeneration. Conditions leading to reaction of degeneration. Prognosis in reaction of degeneration. Anomalous reactions. Sensory nerves. Nerves of special sense. The auditory nerve.

156. **Method of procedure.**—When a patient with any disorder of the nervous system presents himself for electrical treatment, it is nearly always necessary to begin with an investigation of the electrical reactions of his nerves and muscles, for much may often be learned from this procedure of electro-diagnosis, as it is sometimes termed.

It will be found that a considerable amount of care and of time must be devoted to this preliminary investigation; it is not nearly so easy to arrive at clear results as one might be led to expect from the perusal of a chapter on electro-diagnosis. The motor nerves and the skeletal muscles should be investigated first, and both the faradic and the continuous currents must be employed. To simplify matters the unipolar method of excitation must be adopted, the other pole (indifferent electrode) being placed over a distant part of the body, as upon the sternum, or the sacrum or the upper part of the back according to convenience or the requirements of the particular case. *Erb* recommends the sternum as the best position for the indifferent electrode, because it is both symmetrical in position, and is also further removed from the spinal nerve trunks than any part of the surface of the back. The indifferent electrode (fig. 55) should be large, about three or four inches square, in order to overcome the skin resistance, it should be well moistened with water or saline solution (but not so wet as to yield drops of water when moderately pressed) and should be in thoroughly good contact with the surface of the skin in order to provide as many points of entry for the current as possible. The other or exciting electrode must be small for the sake of localising the current to the particular spot required, but not so small as to offer too high a resistance; for faradism, a suitable size is one of about $\frac{4}{5}$ inch (20 mm.) in diameter, for galvanism about $1\frac{1}{2}$ inch (40 mm.) and it must be applied with uniform pressure. It is sometimes useful to fasten the indifferent electrode over the trunk of the nerve supplying the muscles to be tested, in that way the effect of the stimulation can be more easily limited to the muscles under examination. A convenient form of indifferent electrode in such a case is one fastened to a strap or garter of webbing or flannel with a buckle to fix it firmly in place. In examining the condition of the ulnar nerve, for example, in a case of injury to that nerve in the forearm, one should fasten the indifferent electrode over the trunk of the nerve on the inner side of the upper arm, the exciting electrode may then be applied to the interossei or other muscles of the hand which it is wished to test. If the condition of the median nerve is in question one electrode may be applied between the tendons of the palmaris longus and the flexor carpi radialis, and the other as before to the muscles of the hand and fingers.

157. **Comparison of diseased and sound sides.**—The case to be examined may be one in which the mischief (paralysis, anæsthesia or what not) is limited to one part or one side of the body, or it may affect both sides. The first case is the easier because of the advantage of having a sound side for purposes of comparison. If both sides are involved in the disease it becomes more difficult to recognize changes in the electrical reactions, and one has to fall back for guidance upon previous experience, or help may be found in a comparison of one's own corresponding muscles with those of the patient.

158. **Use of the galvanometer.**—First the case of a patient with an affection limited to one side may be considered. It has been shown by *Erb* that it is usual for the two sides of a patient's body to be remarkably equal in their response to stimulation, provided always that the skin resistance of the two sides is the same or nearly so. This skin resistance can be measured by the galvanometer and allowed for. For the most part one does not expect to find much difference in the skin resistance of the two sides, but accidently there may be a difference, and the electromotive force of the testing current must, if necessary, be altered to suit it, by increasing or decreasing the number of cells in the circuit. For instance, if the galvanometer reads 5 milliampères for the minimal contraction when the electrode is applied to the right ulnar nerve, stimulation of the left ulnar nerve should also yield a minimal contraction when the galvanometer reads 5 milliampères, and this whether the number of cells of the battery required to

produce the deflection be the same on both sides or not, for the amount of current entering the nerve is measured by the galvanometer deflection and not by the number of cells. But the galvanometer cannot be used with the faradic current, and as it is usual to commence with that form of stimulus we are compelled to approach the difficulty indirectly, by estimating the strength of the faradic apparatus with a sledge coil (§ 119) and reading off the distance from secondary to primary in millimetres, and by afterwards checking the results obtained in that way by the readings of the galvanometer at the time when the constant current is being used, proceeding in this way the result can be expressed in the form of a table thus:—

HEALTHY MAN (LABOURER).*

	Distances between coils in millimetres		Deflection of galvanometer.	
	Right.	Left.	Right	Left.
Frontal nerve .	165	166	18	19
Spinal Accessory nerve . . .	172	177	16	15
Ulnar	159	158	6	6
Peroneal . . .	160	163	7	9

Here, taking the spinal accessory nerve, the faradic test showed that the left one gave a minimal contraction with the coil at 177 millimetres and the right at 172 millimetres, that is to say the left was more susceptible, the difference being measured by the 5 millimetres increased distance between the coils; this might have been due to a different degree of skin resistance or to a different degree of irritability of the nerve. If it had signified a different skin resistance only, then the minimal contractions to galvanism should have occurred on both sides with the same galvanometer reading, that is to say with the same amount of current in circuit, but the table shows that the left nerve responded with a current of 15° while the right needed a current of 16°; from that we are able to say certainly that the left nerve was slightly the more irritable of the two, and that the difference between the 172 mm. and the 177 mm. was a result of the greater irritability of left over right, and was not due to increased skin resistance on the right side. This example, if thoroughly understood, makes clear the mode of comparing the two sides.

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* This table of Prof. Erb gives galvanometer deflections in degrees, not in milliampères, and the reader must therefore be content to notice that the numbers are comparable for the two sides, although their values are not so directly proportional to one another as if they had been expressed in milliampères.

To measure the strength of the secondary current by the number of millimetres between the primary and secondary coil, has, after all, but little meaning, and does not enable us to compare together the results obtained with different coils, it is a rough means of comparing different patients with the same coil, and that only when the battery which works the coil is acting with uniform strength, and when the contact vibrator is working with the same rapidity and force, and the same objection applies to galvanometers which are graduated in degrees, 5 degrees deflection of one galvanometer may mean something totally different to 5 degrees deflection in another one. The graduation of galvanometers in milliampères enables us to compare the readings of one with those of another, but we are not yet in possession of a simple method of correctly measuring induction currents.

159. **The motor points.**—To continue the examination of the patient; the tests must be applied to the motor nerves, the muscles, and the cutaneous sensory nerves in the parts affected, and they must be compared with the same parts of the opposite and healthy side.

To do this it is absolutely essential to know thoroughly the points where the nerve trunks are most accessible, the motor points of the muscles, and the distribution of the cutaneous nerves.

This requires a certain amount of anatomical knowledge and many diagrams have been prepared as a guide and help to the memory, most of them are based upon *Von Ziemssen's* plates. In the preparation of these plates the stimulation of the nerve trunks, and of the motor points of the muscles was carried out as follows:—The indifferent electrode being placed upon the sternum, a fine pointed exciting electrode of metal covered with wash leather was applied successively to different parts of the muscle under examination, until a position was found (the motor point) where a maximum effect was produced, this was marked with coloured chalk or with nitrate of silver; all the muscles were in turn examined and their motor points marked, the limb with the marks was then photographed. *Von Ziemssen* verified the positions by following the course of the nerves in the dissecting room, and finding where they entered the muscles, and the relation of such points of entry to the surface of the body, he also excited the muscles of bodies recently dead, before the muscular irritability had disappeared, and marking the spots on the surface of the skin where contraction was most readily produced he then cut down and found that the motor point corresponded closely to the point where the nerve entered the muscle.

It should be borne in mind that the motor points are not quite constant for different individuals, their exact place varying a little in different cases, but not so greatly as to diminish the value of knowing their positions. In actual practice the best position of the electrode can be readily found by experiment, by moving it about in the neighbourhood of the usual position of the motor point of any particular muscle until the contraction shows that the exact spot has been touched. The ease with which the motor points can be found depends a good deal upon the amount of subcutaneous fat present, and the examination of the deeper muscles is much more difficult than of the superficial layer, indeed in the case of some of the deep muscles it is almost impossible to produce satisfactory evidence of a contraction limited to the muscle sought, for the diffusion of the current will throw into action the neighbouring superficial muscles and so obscure the result. It is very important to place the patient's limb in a good position, so that any muscular movement looked for may be readily seen ; the muscles must be lax, the limb should be supported by the hand of the operator, and not lying flat upon the table or couch. It is best to begin with a current which is strong enough to throw the muscles into contraction and to apply it only for a very brief moment at a time, in this way the patient will be less alarmed, and the process of testing will be sooner over. It is well always to try the strength of the current on oneself before touching the patient.

It is assumed that the action of the individual muscles is known, so that when a contraction is produced, it can be referred to its proper muscle. The actions of the muscles were elaborately studied by *Duchenne*, as one of the outcomes of his methods of treatment by localised application of the faradic current to paralysed muscles, and he has described them at great length in his *Physiologie des Mouvements.* Besides watching for and seeing the movement produced by the contracting muscle, one may often feel a weak contraction by placing the hand over the tendons lightly, or one may see or feel movements of the fibres of the muscle itself when they are two feeble to move the bone to which the muscle is attached.

The subjoined table of the points at which certain nerves may be conveniently stimulated will be of service, and Plates I. to VI., which show the motor points, must be continually referred to until they are known by heart. The areas of skin which are served by the several cutaneous nerves must also be thoroughly mastered; *Heiberg's* "Atlas of the Cutaneous Nerves," translated by *Dr. Wagstaffe*,* has some useful coloured outlines of these areas of distribution. *Prof. Flower's* "Atlas" may also be referred to. (See Plates VII. to XI., after *Flower* and *Ranney*).

Points favourable for the electrisation of nerves.

In the upper limb:—

1. *The median*, along the inner border of biceps, and at the bend of the elbow.
2. *The ulnar*, in the groove between the internal condyle and the olecranon.
3. *The musculo-spiral*, at the point where it emerges from the triceps; namely, on the outer side of the upper arm about the junction of its middle and lower thirds.

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* Baillière, Tindall and Cox, 1885.

4. *The musculo-cutaneous*, in the hollow of the axilla.
5. *The brachial plexus*, in the hollow above the clavicle.
6. "At a spot 2 or 3 centimetres above the clavicle and a little externally to the posterior border of the sterno-mastoid, immediately in front of the transverse process of the sixth cervical vertebra, a simultaneous contraction can be produced in the deltoid, biceps, brachialis internus and supinator longus." This point has been called the *supra-clavicular point* of Erb.

In the lower limb:—

7. *The anterior crural*, in the fold of the groin just outside the femoral artery.
8. *The sciatic*, in the pelvis, through the coats of the rectum; or just below the gluteal fold at the back of the thigh.
9. *The peroneal*, just above the head of the fibula, beside the biceps tendon.
10. *The tibial nerve*, in the popliteal space, and to the inner side of the tendo Achillis.

In the face:—

11. *The facial*, through the cartilage of the lower surface of the meatus auditorius. Its chief ramifications can be reached where they emerge from the parotid gland. *Erb* chooses for stimulation three main branches of the facial: (*a*) for muscles above palpebral aperture; (*b*) for muscles in front of upper jaw, between the orbit and the mouth; (*c*) for muscles of the lower jaw. He tests each of these in two places, first at points just in front of the ear, and secondly for (*a*) at the temple, for (*b*) at anterior extremity of zygomatic bone near its lower border, for (*c*) at the middle of the inferior border of the horizontal ramus of the lower jaw.

12. *The fifth*, at the supra-orbital foramen—at the infra-orbital foramen—at the foramen mentale, on the side of the tongue, on the outside of the cheek.

In the neck :—

13. *The spinal accessory*, at the top of the supra-clavicular triangle, where the nerve pierces the sterno-mastoid.
14. *The phrenic*, on the outer edge of the lower part of the sterno-mastoid.
15. *The hypoglossal*, along the upper border of the great cornu of the hyoid bone.
16. *The recurrent laryngeal*, along the outer border of the trachea.
17. *The pneumogastric* and *glosso-pharyngeal* along the track of the carotid artery just below the angle of the jaw.

160. **Relation of spinal nerve roots to muscles.**—Frequently it happens that paralysis affects a group of muscles; in these cases much light may be thrown upon the diagnosis if it is possible to trace back the nerve supply of the affected muscles to their spinal roots. This is not always easy, particularly when the nerve trunks pass through a plexus like the brachial plexus on their way from the cord to the muscles; for example, the distribution of a paralysis affecting some of the muscles of the hand might enable us to distinguish between a lesion of the trunk of the median nerve on the one hand, and a lesion of the eighth cervical and first dorsal roots on the other; in the latter case the whole of the thenar and hypothenar eminences and all the lumbricales and interossei would be paralysed; in the former case some of these muscles would escape, namely, the hypothenar, the interossei, the two inner lumbricales, the adductor pollicis, and the inner half of

the flexor brevis, all of which are supplied by the ulnar nerve.

A paper published in "Brain," 1881, by *Dr. Ferrier*, gives a tabular statement of the more important spinal nerve roots, with the muscles supplied by each. As it is likely to be of great value in electrical diagnosis we reproduce it here, as modified by *Dr. De Watteville*, "Lancet," July 14, 1883.

Nerve roots :—

4*th cervical.*—Deltoid, rhomboids, spinati, biceps ; brachialis anticus, supinator longus ; extensors of hand.

5*th cervical.*—Deltoid (clavicular portion), biceps ; brachialis anticus, serratus magnus, supinator longus; extensors of hand.

6*th cervical.*—Latissimus dorsi, pectoralis major, serratus magnus, pronators, triceps.

7*th cervical.*—Teres minor, latissimus dorsi, subscapularis, pectoralis minor, flexors of hand, triceps.

8*th cervical.*—Flexors of wrist and fingers, muscles of hand, extensors of wrist and fingers, triceps.

1*st dorsal.*—Muscles of hand (thenar, hypothenar, interossei).

3*rd lumbar.*—Ilio-psoas, sartorius, adductors, extensor cruris.

4*th lumbar.*—Extensor femoris et cruris; peroneus longus ; adductors.

5*th lumbar.*—Flexors and extensors of toes—tibial, sural, and peroneal muscles, extensors and rotators of thigh, hamstrings.

1*st sacral.*—Calf, hamstrings, long flexor of great toe, intrinsic muscles of foot.

2*nd sacral.*—Intrinsic muscles of foot.

Reference to the paper of *Dr. Ferrier* will show that in his table the function of each nerve root is expressed in terms of the movements produced, and not in terms of the muscles concerned in producing the movements.

Dr. Herringham[*] has also tabulated as follows the results of numerous dissections of the brachial plexus in new-born infants.

Usual nerve supply :—

3rd, 4th and 5th cervical.—Levator anguli scapulæ.

5th.—Rhomboids.

5th or 5th and 6th cervical.—Supraspinatus, infraspinatus, teres minor.

5th and 6th cervical.—Subscapularis, deltoid, biceps, brachialis anticus.

6th cervical.—Teres major, pronator teres, flexor carpi radialis. Supinator, longus and brevis. Superficial thenar muscles.

5th, 6th and 7th cervical.—Serratus magnus.

6th or 7th cervical.—Extensores carpi radiales.

7th cervical.—Coracobrachialis, latissimus dorsi, extensors at back of forearm, outer head of triceps.

7th and 8th cervical.—Inner head of triceps.

7th, 8th and 1st dorsal.—Flexor sublimis and profundus, flexor carpi ulnaris, flexor longus pollicis, and pronator quadratus.

8th cervical.—Long head of triceps, hypothenar muscles, interossei, deep thenar muscles.

The *pectoralis major* from 6th, 7th, 8th and 1st dorsal.

The *pectoralis minor* from 7th, 8th and 1st dorsal.

Dr. Gowers[†] also gives a table of the "approximate relation" of the spinal nerve roots to the various motor, sensory and reflex functions of the spinal cord.

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[*] "Proc. Roy. Soc." March, 1866.

[†] "Diseases of the Nervous System," vol. i., 1886.

161. **Importance of experiments.**—When the student has acquired by practice a fair degree of proficiency in finding the motor points he will have conquered the chief difficulties of the investigation of the reactions of a patient's muscles. Nothing is so useful as to practise frequently upon oneself, and the unreasoning dislike which many people have to applying currents to their own persons is much to be deprecated. A faradic current which is strong enough to provoke contraction in the muscles is not really painful, and it certainly inspires confidence in the patient if he sees the physician begin by applying the current to his own muscles. Sometimes the current applied is not strong enough, and thus the mistake may be made of supposing that muscles do not respond to faradism when really they would respond readily if a sufficiently strong current were used.

162. **Bilateral affections—Prof. Erb's method.**—Before speaking of the deviations from the normal standard which are met with in disease it would be well to quote from *Erb* his account of a plan for dealing with cases having lesions of both sides of the body, and in which comparisons between a sound side and a diseased one are not possible. He says: "in order to eliminate the necessity of comparison with other individuals, and to find a standard of comparison on the same person, I have tried a wider method of exploration. It consists in determining the excitability of nerves in different regions of the body, and afterwards comparing the results and fixing the relative value in different individuals. We find a fairly constant correlation between the four pairs of nerves we have chosen, so that too considerable deviations of one of them with reference to the relative value may be considered as patho-

logical." "Hence the following method:—In testing we must always choose these four nerves—the *frontal* nerve or branch of the facial nerve supplying the *frontalis* muscle, the *accessory* nerve, the *ulnar* nerve at the elbow, and the *peroneal* nerve. On each of these nerves we must determine with great care with a fine electrode, on the most excitable spot, the distance of the coils at which the minimum faradic contraction occurs, this is done by marking the number at which the weak but visible contraction is obtained with the negative pole of the secondary coil. Then by means of the galvanic current and with a middle sized electrode, moistened with hot water every time it is applied, the galvanometric deviation is determined with a definite number of cells (ten or twelve). The positive pole remains fixed upon the sternum, and the negative is applied to all the spots at which the excitation is made. The numbers thus found are tabulated."

"We thus obtain two series of numbers, the one representing the relative faradic excitability of the four nerves, the other the relative state of the resistance at the corresponding points on each side of the body. I have already pointed out how the results of the second series assist the conclusions to be drawn from the first" (see table, § 158). "From this table we learn that the numbers obtained for either side of the body coincide almost exactly, further, all four pairs of nerves are excited by minimum currents of sufficiently comparable strength; the relation between the ulnars and peroneals in this respect is of special import, they require almost equal distances of coils, while the frontals often respond to a distance slightly less (a slightly stronger current) and the accessories to one a little greater (a slightly weaker current)." "I think it well to direct your attention here to some of the difficulties and sources of error which you may have to encounter. In the first place you must find the place where the nerve is most excitable, and then determine the weakest current which will excite it. Much skill and patience are required for this, it is wonderful to see how slight a movement of the exciting electrode will produce a wholly different effect. Special difficulties arise in connection with the ulnar and peroneal nerves; the situation in which the former is most excitable is about three centimetres above the internal condyle, at the inner border of the triceps; in the case of the peroneal it is three or four centimetres above the head of the fibula, beside the tendon of the biceps, and can be reached with the electrode only after much searching."

By making oneself thoroughly familiar with the behaviour of these four nerves in a series of healthy patients, one obtains a standard which is of great value in the investigation of cases of disease, for instance the following table given by *Erb* from a case of *tabes dorsalis*, illustrates his meaning and shows a change in the direction of increased faradic excitability in the peroneals :—

DISTANCE BETWEEN COILS IN MILLIMETRES.

	RIGHT.	LEFT.
Frontal	170 ...	168
Accessory ...	166 ...	167
Ulnar	170 ...	165
Peroneal	205 ...	200

163. **Electro-diagnosis charts.**—*Dr. Leslie Phillips* has drawn up a very useful chart for recording the results of the electrical investigation of nerves and muscles in which he has very conveniently utilised the sugges-

tions of *Prof. Erb.* His instructions for using them are subjoined.

"Securely fasten a large plate electrode, well moistened with warm water, to the sternum or nucha. 1. Begin by finding minimal reaction of nerves and muscles to faradic current, using an electrode about a centimetre in diameter. 2. By means of a larger electrode placed over the same points, pass a galvanic current from ten cells, and note deflection of needle of galvanometer. This will detect differences of resistance on the two sides—the less the deflection the greater the resistance. 3. Next pass to galvanic current and observe the needle deflection at which first contraction appears (*a*) on closing, and (*b*) on opening the current with the kathode, and then the same with the anode, on the nerve or muscle. For galvanic observations use an electrode two centimetres in diameter. Choose perfectly symmetrical points to compare right and left. Dip the electrode in water each time before applying to the skin. Do not allow the current to flow longer than is needful for making the observation, so guarding against electrotonic error."

164. **Morbid changes in the electrical reactions.**—The changes in the electrical reactions which are found in disease may be classed as follows:—

A. *Motor.*

1. Increased excitability	(*a*) faradic (*b*) galvanic	Quantitative changes.
2. Diminished excitability	(*a*) faradic (*b*) galvanic	
3. Reaction of degeneration	(*a*) complete (*b*) partial	Qualitative changes
4. Other motor anomalies		

B. *Sensory.*
  1. Increased excitability.
  2. Diminished excitability.

165. **Quantitative changes.**—(*a*). *Increased or decreased irritability to faradism.*—Before forming a diagnosis of an increase or decrease of excitability it is necessary to keep steadily in mind the importance of measuring the resistance of the patient at the same time, because without the galvanometer it is not easy to know how much of the result depends upon altered resistance and how much on altered excitability.

In unilateral disease increased or decreased faradic excitability is shown by difference in behaviour of the two sides. If the normal side be first tested and the distance in millimetres of secondary from primary be taken with the minimal stimulus, an increase of excitability will be shown on the affected side if the minimal contraction shows itself with a greater distance between the coils. If both sides are affected, then an increased faradic excitability is inferred if the minimal stimulus is seen with the secondary further from the primary than the distance which the operator has taught himself to recognise as usual in healthy people; and the inference is supported if the galvanometer shows that there is no abnormal diminution of resistance; or by *Erb's* method the comparison of frontal, accessory, ulnar and peroneal nerves may show an order of excitability unlike that of health; it is not often that all four of these nerves are involved for both sides, situated as they are in parts of the body remote from one another.

(*b*) *Increased or decreased galvanic excitability.*—Galvanic increase of excitability is shown by the development of KCC with a smaller galvanometer deflection than usual, by the ready production of KD, and generally by the easier production of all the contractions.

Galvanic diminution of excitability is shown by increased difficulty in the production of all the contractions till a stage is reached when only KCC can be obtained even with strong currents, and finally this reaction also may disappear; galvanic excitability is then said to be lost or abolished.

Increased excitability of the nerves and muscles is not very common, when it does occur it represents phases of irritation, and therefore it is most common in the early stages of several disorders (such as tabes, chronic myelitis, hemiplegia) where at a later period the reactions become diminished.

Diminished excitability occurs in many old standing nervous diseases, in myopathic muscular atrophies, in some cases of peripheral neuritis (alcoholic and other) in paralysis or atrophies after joint diseases. Its recognition is important, and particularly so when the diagnosis rests between it and the reaction of degeneration.

166. **Qualitative changes—The reaction of degeneration.**—This term was introduced to signify the altered electrical reactions which occur in nerves and muscles under certain special pathological conditions; the peculiar feature being that the change is not only a quantitative one, but also a qualitative one; that is to say, there is an alteration in the nature of the response which the degenerate muscles make to the continuous current. KCC becomes less easily elicited than ACC (see § 144), and in addition, the contraction, when it is provoked, is a slow and sluggish one, differing greatly from the very rapid contraction given by a normal healthy muscle. *Erb's* definition of the reaction of de-

generation is the following. "It is characterised by the diminution and loss of faradic excitability in both nerves and muscles, whilst the galvanic excitability of the latter remains unimpaired,* is sometimes notably increased, and always undergoes definite qualitative modifications."

This reaction of degeneration, often symbolised by the abbreviation RD, is of very great importance. Its discovery and development arose from an observation of *Baierlacher* in 1859, that the muscles in a case of facial paralysis did not respond to faradism, but reacted with unusual force to galvanism, and to *Erb's* careful study of the symptom then first made known we owe the most important fact connected with the subject of electro-diagnosis.

The investigation of the reaction of degeneration has been pursued both clinically and experimentally, and its value consists in the fact that when it is present we may diagnose a break in the nervous tract reaching from the end plate of the muscle to its "nucleus of origin" in the grey matter of the anterior cornu of the spinal cord; the lesion therefore must either be in the grey matter of the anterior horn in the cells where the nerve fibre starts, or in the course of the nerve fibre from there to the muscle. The reaction of degeneration does not follow lesions which are above the spinal ganglion cell whence the nerve fibre springs (see table, p. 249), nor does it follow affections which are confined to the muscle fibres proper (idiopathic muscular atrophies).

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* *Mr. Bowlby* in his Lectures on Injuries of Nerves, delivered at the Royal College of Surgeons, in June, 1887, says that in his experience diminution of the excitability to galvanism is much more common than increased excitability. He says, "I have never seen but once the least increased excitability, on the contrary, I have found that the galvanic irritability diminished rapidly, so that in two or three weeks, at a time when theoretically excitability should be at its height, strong currents produced but slight contractions, which were also very slow and wavy." *Mr. Bowlby's* experience is possibly due to his experiments having been made chiefly on the hand. A comparison of the excitability of the muscles of the hand with those of the forearm, very often shows an apparent decrease of irritability in the former, but this is due to the greater thickness of the skin of the hand which offers a high resistance (see above, § 158).

In RD the irritability of the nerve disappears entirely, and therefore stimulation of it has no effect, the muscle on the other hand retains its irritability to the galvanic but not to the faradic current, that is to say its irritability is still present for certain stimuli, and its contraction wave can be transmitted from muscle fibre to muscle fibre, much as it is in a curarised muscle. It does not react to faradism, perhaps because the faradic shocks are too brief, but it reacts to the stimulus of a smart blow as it does to a galvanic current slowly made and interrupted. A curarised muscle will still react to faradism, though not so readily as a normal muscle, therefore the total loss of faradic irritability in a muscle showing the reaction of degeneration signifies something more than a torpor of the intramuscular nerve endings, it means that a trophic change has occurred in the muscle protoplasm, and further evidence of the change is seen in the production of ACC more easily than KCC. This alteration of irritability is an extremely important part of the reaction of degeneration, for it is exactly the reverse of what is found in healthy muscle. Another important alteration is that the galvanic irritability of the muscle may be greater than in health, KCC being more easily produced than before, and therefore ACC far more easily than before, because in health ACC requires a stronger stimulus than KCC, in the proportion of 2 : 1 (§ 144).

It is not always that the phase of exaltation of muscular irritability is manifested, and in most cases of RD, that is, of course, if recovery does not set in, the later stage is one of gradual failure of the galvanic irritability of the muscle; ACC, however, being always the more easy of the two to provoke, and in the last stage of all, ACC alone may remain, faintly responsive to strong currents.

167. **The course of the reaction of degeneration.**—At first for two or three days after the onset of the lesion there will be in the *nerve* a progressive lowering of the galvanic and faradic irritability, then by the second or third week the galvanic and faradic irritability of the nerve will be completely abolished—and it will remain so unless recovery takes place; in that case the return of motor power may precede the return of electrical irritability.

In the *muscle* the reaction to faradism runs the same course as in the nerve. To galvanism, on the other hand, there is at first a progressive lowering of excitability, but by the end of the second week this is replaced by an increase of excitability to a point much above the normal with sluggishness of contraction and ACC > KCC; after a period of three, six, or eight weeks diminution of excitability sets in, and the diminution is progressive until at last it becomes stationary as a mere trace of ACC.

In cases which recover it may happen that the voluntary power of movement will return long before the nerve can be made to respond to electrical stimuli, but more often the one recovers with the other.

The following is an account of the course of the changes which occur in a typical case of RD after division of a nerve trunk.

1. A sudden arrest of voluntary motion in the muscles supplied by the divided nerve.

2. Arrested conductivity of the nerve—therefore abolition of excitability to faradism in the muscles supplied from below the wound when both electrodes are placed on or near the nerve trunk above the seat of injury.

3. For two or three days, sometimes only for forty-eight hours, faradic contractility remains present in the muscles when the electrodes are applied on the distal side of the section or on the bodies of the muscles. The disappearance of the reaction to faradism shows degeneration of the intra-muscular nerve fibres and end plates.

4. Increased galvanic irritability accompanied by a relative increase of anodal excitability. The anodal closing contraction (ACC) approaching in amplitude and ultimately exceeding (about the sixth or seventh day) the cathodal closing contraction (KCC). The electrodes are applied, one on an indifferent part of the body, and the other on the muscle deprived of its nerve supply, and the direction of the current alternated on purpose to compare the amplitude of the contractions produced. The current is conveyed, not by the nerve, the continuity of which is severed, but more or less by all the tissues of the body intervening between the two electrodes.

5. During this period the muscular fibrillæ are losing their striated appearance and are undergoing some change in their constitution. The nuclei then increase in number and there is a proliferation of the connective tissue between the fibrils. This ultimately will lead to a cirrhotic condition in the muscle and to a decrease of the increased galvanic irritability.

6. As the muscle degenerates and the cirrhosis in-

creases the galvanic irritability steadily declines, still showing with decreasing force the ACC>KCC. The final disappearance of galvanic irritability may not take place for many weeks or months.

7. If union of the divided nerve takes place, the axis cylinder is first restored, at any time from the end of sixth week to the seventh or eighth month, and voluntary movement in the muscles again becomes possible.

8. Lastly, after the regeneration of the nerve, muscular regeneration commences. The cathodal closure contraction gradually re-asserts itself, and the galvanic irritability again very gradually rises to its former condition under which it existed before the nerve was divided.

Such is a review of the typical electrical reactions of nerve and muscle after complete severance of a nerve, and these reactions modified in various ways, by the amount of destruction to the motor centres or cells, or the conducting nerve fibres, are characteristic of the several nervous diseases in which qualitative changes in the electrical reactions are to be observed.

Professor Erb is careful to remind his readers that various deviations from the typical form of the reaction of degeneration may be met with. He says: "You must not expect to find in every pathological condition so great a uniformity in the course of these modifications as is to be met with in experiment, or in a simple traumatic lesion of the nerves; this does not often occur in disease, where many deviations may be caused by the nature of the injury, different affections of trophic influences, occasional improvement, or new elements of disturbance following one upon another; and one is not warranted in concluding from some irregularity, such as presents itself in long-standing cases, that one has discovered some fresh anomaly. The time at which repair takes place determines great differences in the general manifestation of the reaction of degeneration. If this happens early the nerve may be endowed with galvanic and faradic excitability while the changes in the muscle are at their height, these latter cannot be reformed so quickly, and require for the purpose some lapse of time. It may happen then, that when the nerve is excited the muscle responds with normal contractions, but still when stimulated directly exhibits the reaction of degeneration. But if repair sets in very late, it may be that the muscular galvanic excitably is already greatly diminished when the electric excitability of the nerve begins to be slowly restored. There is, therefore, an indefinite number of special cases, which nevertheless may be mastered by carefully attending to the conditions of time and other circumstances."

168. **Partial reaction of degeneration.**—Under this name *Erb* has brought together and grouped certain deviations from the normal type; in these, the behaviour of the muscle to galvanism is entirely that of the typical RD while the behaviour of the muscle to faradism is much the same as in normal muscle, showing only slight quantitative diminution, and the behaviour of the nerve also is merely a slight quantitative diminution to galvanism and faradism with no qualitative alteration. The galvanic reactions of the muscle show ACC > KCC, a considerably exalted excitability, and the sluggish mode of contracting.

Muscles having the partial reaction of degeneration may exist in a limb side by side with others showing the complete form, and other muscles may show other degrees of transition between the normal state and partial or complete degeneration, but the existence of such

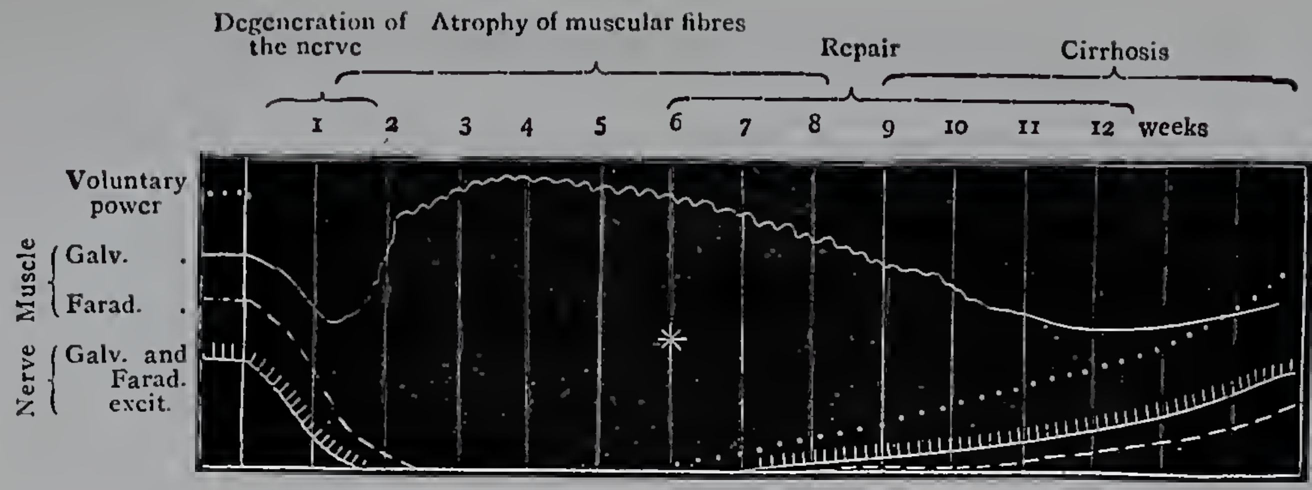

FIG. 70.—Paralysis with comparatively speedy restoration of voluntary power.

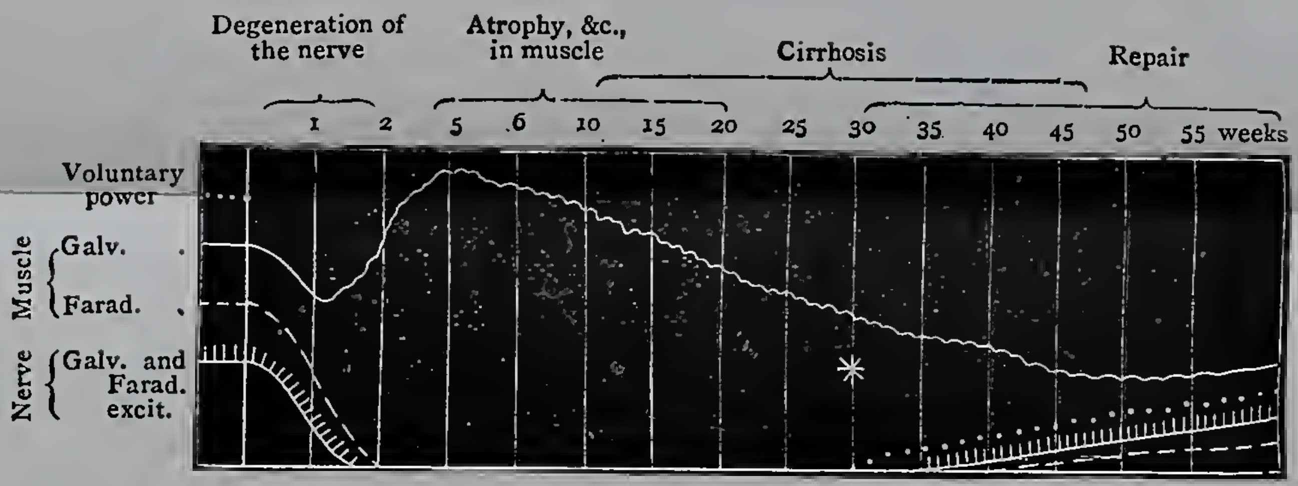

FIG. 71.—Paralysis with more tardy restoration of voluntary power.

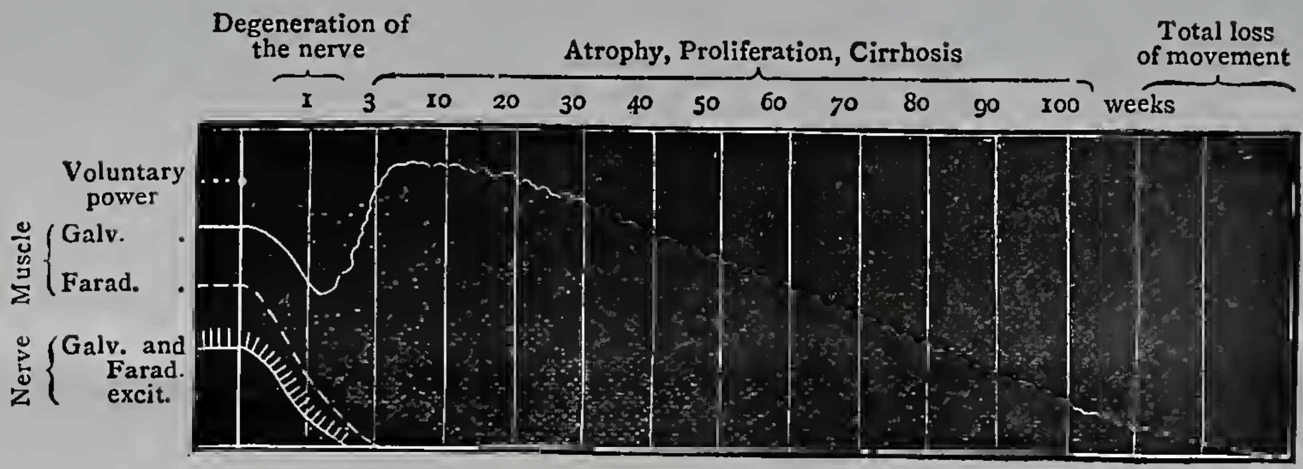

FIG. 72.—Incurable paralysis. Voluntary power unrestored.

Figs. 70, 71, 72, are diagrammatic representations of the complete form of the reaction of degeneration, showing the changes in the degree of voluntary power and in the faradic and galvanic excitability of the nerve and muscle in three different cases (*Erb*).

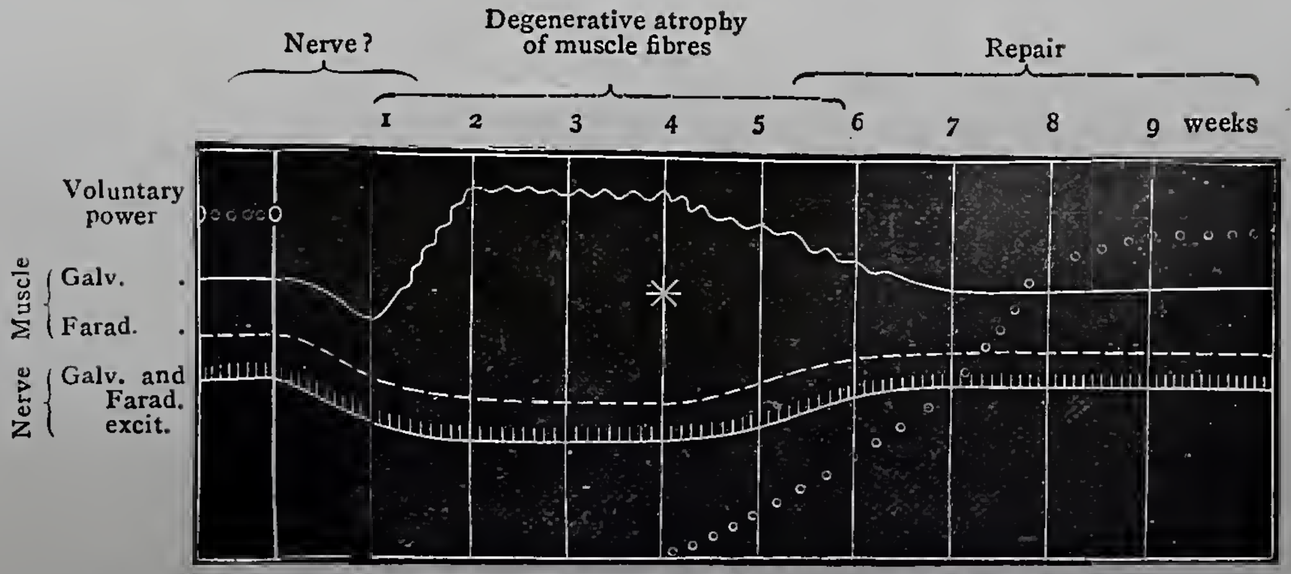

FIG. 73.—Graphic representation of the partial form of RD. The faradic and galvanic excitability of the nerve, and the faradic excitability of the muscle, are but slightly lowered. Voluntary power soon restored. Recovery rapid and complete. There was probably no degeneration of the nerve (*Erb*).

In each figure the first thickly lined ordinate represents the date of the injury. Voluntary power is at once abolished, its return being indicated by the asterisk.

a condition as that in which the muscles show a reaction of degeneration, though connected to the central nervous system by a nerve still functional, or at least capable of conducting impulses to the muscle, makes it more than ever difficult to understand the exact meaning of the muscular changes which give rise to the phenomena of the reaction of degeneration. *Erb* especially insists that although the partial form could be simulated by the particular case of commencing recovery from complete reaction of degeneration, yet the two states are different; for that the partial reaction of degeneration may be present at the commencement of an attack, and may be followed at a later period by the complete form in the same nervous and muscular structures. The accompanying charts of *Prof. Erb* (figs. 70, 71, 72, 73) represent the phenomena of the reaction of degeneration in a graphic manner.

The increased excitability of the muscle to galvanism is in marked contrast to the diminished reactions of the nerve to galvanism and faradism, and of the muscle to faradism.

169. **Conditions which lead to the reaction of degeneration.**—Briefly speaking, RD follows upon damage in that region of the motor path to which *Dr. Gowers* has given the name of the "lower segment," that is to say, that part of the course of a motor fibre which commences at the motor ganglion cell of the anterior cornu, and is continued down as a nerve fibre to the motor end-plate beneath the sarcolemma of its muscle.* It

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* "It is worth while to consider for a moment the whole motor path, from the cortex of the brain to the muscles; we may consider it as composed of two segments, an upper and lower, each consists of a ganglion cell above, a nerve fibre, and the terminal ramification of the latter; the upper "cerebro-spinal" segment consists of the cor-

does not follow damage limited to the "upper segment." RD then will occur after division, destruction or injury of motor nerve trunks, and after disease or injury affecting the ganglion cells of the anterior cornu of the cord. Under one or other of these morbid states can be grouped pressure palsies of all kinds, different forms of peripheral neuritis, division or laceration of nerves, poliomyelitis anterior both acute and chronic, progressive muscular atrophy, if of spinal origin (but not if of muscular origin), also lead poisoning, acute and chronic myelitis, and diphtheritic paralysis. The reaction of degeneration is not found in the paralysis of cerebral disease (except when the implication of the nuclei of origin or of the nerve trunks of the cranial motor nerves produces a reaction of degeneration in the muscles which they supply) nor does it occur in diseases limited to the white matter of the cord, nor in hysterical paralysis.

*Dr. de Watteville** has drawn up the table on page 249 for a guide to the position of a lesion so far as it is indicated by the electrical reactions.

170. **Prognosis in the reaction of degeneration.** —"Other things"—that is the cause and nature of the disease—"being the same, the lesion is serious, the probable duration of the disease longer, the definite

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tical ganglion cell, and the pyramidal fibre which proceeds from the cell, passes through the brain and cord, and ends by dividing in the spongy substance of the anterior cornu. The lower "spino-muscular" segment consists of the spinal ganglion cell, and the fibre proceeding from this, passing from the anterior root and nerve trunk of the muscle, where it divides and ramifies on the muscular fibre........... It will be found that this conception of the motor path conduces to clearer ideas of many phenomena of disease." *Gowers*, "Diseases of Nervous System," 1886, vol. i., p. 116.

* "Lancet," July 14th, 1883.

prospect of a cure more remote, in proportion as the reaction of degeneration is developed and complete, and in proportion to the stage which it has reached" (*Erb*).

TABLE FOR LOCALISATION OF A LESION FROM THE ELECTRICAL REACTIONS.

A. Normal	1. Healthy (shamming). 2. Functional disturbance of 3. Organic ,,	Cortex. Corpus striatum. Peduncles. Pons. Lateral columns. Peripheral nerves (very slight disease). Muscles.		
B. Abnormal	Quantitative alterations.	Augmented irritability.	Irritative process in	Brain. Lateral column.
			Hyper-excitability in	Cornua. Nerve-muscle.
		Diminished irritability.	Alterations in nerve-muscle of spinal origin. Alterations in nerve-muscle of idiopathic origin. Alterations in nerve-muscle of post-regenerative origin.	
	Quantitative and Qualitative.	Complete reaction of degeneration.	Destruction of anterior horn. Disease of multipolar cells. ,, trophic centres of nerve-muscle. Severe lesion of nerve trunk.	
		Partial reaction of degeneration.	Slight disease of multipolar cells. Disease of trophic centres of muscle. Slight disease of nerve trunk.	

He instances the value of the symptom in the prognosis of simple facial palsy, distinguishing three forms. (1) *Mild*, electrical reactions normal, prognosis favourable, probable duration three weeks. (2) *Intermediate*, partial RD, duration one or two months. (3) *Serious*, complete RD, prognosis bad, duration 3, 6, 9 months or longer.

At the same time he emphasizes the importance of the saving clause with which the quotation opens, insisting that it is not permitted to reason alike in all paralyses, without giving due weight to the importance of the lesion producing them, for instance the prospects of a case of facial palsy from caries of the petrous portion of the temporal bone cannot be expected to resemble those where the mischief has been set up by a mere exposure to cold; and electrical reactions which are a guide to prognosis in cases of the latter type must not be forced into a similar interpretation for the former. There is an important remark of *Dr. de Watteville's* from the paper quoted above:—" It may not be unnecessary to guard the student against the error of looking upon the occurrence of alterations in the response of nerves and muscles as in itself indicative of irreparable mischief. On the contrary, RD is often of far more favourable prognosis than normal reactions, which we have already found to be consistent with absolutely incurable lesions, involving complete paralysis. Intractable spasms, tremors, or convulsions again are never accompanied by any notable disturbance, quantitative nor qualitative, of the electrical reactions."

171. **Anomalous electrical reactions.**—(*a.*) *RD or partial RD occurs in muscles which are not paralysed.* This condition of affairs was first described by *Erb*, but it has since been noticed by *Bernhardt*, *Kast*, *Buzzard*, *Hughes Bennett* and others. Many of the cases recorded have been in people showing signs of lead poisoning, though not all were such, and for the most part the nerves responded to faradism and galvanism, though not quite so well as in health, while the muscles showed the alterations of the reactions of degeneration (partial RD); in others the reaction of degeneration was complete, the nerves responding not at all to faradism or galvanism.

(*b.*) *The muscles respond by a sluggish contraction to a stimulus, either faradic or galvanic, applied to the nerve trunk.*

(*c.*) *The muscle responds in a similar sluggish manner to* *faradic currents applied to the muscle itself.* The reader who wishes to master the intricacies of this part of the subject should consult *Professor Erb* in *Von Ziemssen's* volume on "Electrotherapeutics," p. 208-225, where he will find a description of several rare variations from the usual course of reaction of degeneration.

172. **Sensory nerves.**—There is but little to be said on the subject of alterations in the electrical reactions of sensory nerves. Simple increase of sensibility and simple decrease of sensibility can be detected, and apparently the degree of electrical sensibility corresponds rather with the degree of perception of pain than with that of perception of tactile sensations. This has been determined in locomotor ataxy where these two forms of sensibility are often affected in unequal degrees.

For investigating the electro-cutaneous sensibility it is as important to notice and take into consideration the amount of skin resistance, as it was in examining the muscles, and where exact results are wished for, the sledge form of coil must be used, and the distance of secondary coil from primary must be noted and recorded. For testing the sensibility of the cutaneous nerves one should use a metallic brush for the active electrode and should not moisten the surface of the skin; or an electrode devised by *Erb* may be used. It consists (fig. 74) of a bundle of 400 metallic wires sheathed and varnished, enclosed in a vulcanite case of about two centimetres in diameter. At one end the wires are all put in metallic communication, and are attached to an ordinary rheophore handle, the other end is polished, so that when applied to the skin it has the effect of a smooth surface. It covers an area of skin of about two centimetres in diameter, and into this the current enters in 400 parts. Thus a more regular action on the numerous nerve terminations is secured, and with the faradic current the degree of stimulus may be estimated for the first appearance of sensation, and for the first perception of pain. The following remarks* on the subject of estimating anæsthesia, are of great value in showing how easy it is to be misled in testing a patient for anæsthesia. "The patient should always be placed in such a position that it is impossible for him to see the hand of the surgeon, or the area which is under observation. He should not be allowed to move the finger or other part touched, for thereby the muscular sense comes to the aid, and falsifies observations. The impact of the instrument used should be very light, for a patient can frequently discern friction on an anæsthetic surface by means of vibrations carried by the tissues to surrounding healthy nerves.........I have often

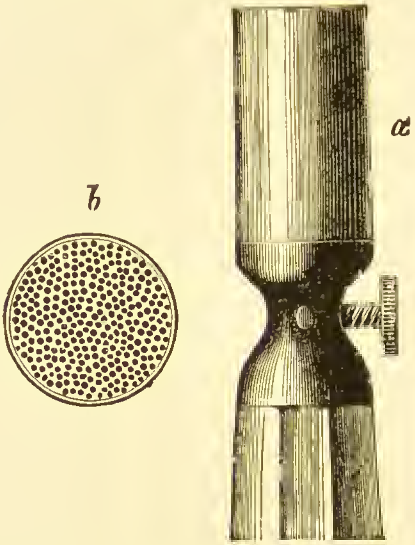

FIG. 74.—Cutaneous electrode. *a*. Side view. *b*. End view.

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* "Lectures on Injuries of Nerves," *Lancet*, June, 1887. *A. A. Bowlby*.

seen the sensory power of a presumably anæsthetic part tested by rubbing the part with the finger while the patient's eyes were averted, and almost always with the result that the stimulus was correctly perceived, and that a returning sense of touch was diagnosed by the investigator. Such a conclusion is entirely erroneous, for as *Létiévant* has pointed out, any person can perceive friction applied even to the finger of another person, if it be held between the bases of two of his own fingers, *i.e.*, the vibrations are conveyed to and appreciated by the nerves of the surrounding digits. How much more must this be so in the case of a divided median nerve when healthy nerves are present on part of the very finger to which the friction is applied. Friction should, therefore, never be used as a test of sensation, for the same reason the part which is being examined should never be pushed or thrust away from the position in which it lies."

173. **Nerves of special senses.**—*The auditory nerve.*—Of the nerves of special sense there is one which we may discuss at present, namely, the auditory, because of the importance which the electrical treatment of *tinnitus aurium* has given to it. We have already (§ 149) pointed out that in health it is possible to obtain reactions when a galvanic current passes through the auditory nerve, and that like the motor nerves, the auditory responds more readily to KC than to AC, and generally exhibits the same electrical reactions, the response being the production of a subjective sensation of sound; but in certain cases of *tinnitus* the auditory nerve answers to electrical currents much more readily than it does in health, being affected even by a current of the strength of one milliampère. In these cases it is supposed that there is a state of hyperæsthesia or of irritation in the

nerve, and that the tinnitus is really the expression of that irritable state. In the simplest form of hyperæsthesia the kathodal closure gives loud sounds which readily persist so long as the current is flowing (KD) but cease at once with the opening of the circuit, while the anode (anodal closure) diminishes or abolishes the sound, which does not return during the passage of the current, and often not for hours after the current has been stopped, provided that the stoppage be very gradual, so as to diminish as far as possible the effect of anodal opening.

In the examination of the reactions of the auditory nerve there are many difficulties, first in the application of the current without producing fresh noises from accidental movements of the electrode, second, from the tendency of the other ear to respond and so confuse the results.

To apply the current to the auditory nerve it has been recommended that the patient should sit down with his head resting on a table, in such a way that the ear to be treated is uppermost; the external auditory meatus can then be filled with water, and the electrode introduced into it just so far as to dip into the water; the other electrode may be applied to the sternum, to the nape of the neck, or may be held in the hand, or it may be arranged underneath the other ear, the side of patient's head resting upon it, the current is then gently and gradually turned on.

Of these several positions of the indifferent electrode the last is probably the worst, for it is difficult to see how the effect of the anode can be brought to bear upon one ear without at the same time producing a kathodal zone near the other ear; but wherever the negative electrode may be placed, there is always some likelihood, if both ears are very sensitive, that the ear not operated on may give responses, coming as it does within a region of virtual kathode (§ 145) when the anode is applied to the other ear, and *vice versâ*, and indeed if one ear be much more sensitive than the other the application of a current to the less sensitive one may produce sounds in the opposite ear only, and then the normal formula of the auditory nerve may appear to be reversed, the responses being produced by a virtual kathode in the more sensitive ear when the actual anode is applied to the other, and so on, a state of things very likely to confuse the experimenter, particularly when his patient is not very intelligent. This reaction of the opposite ear has been called the "paradoxical reaction."

When the external auditory meatus has been filled with water, the sensation is so uncomfortable and the external sounds are rendered so strange and booming, that it is a matter of difficulty to be sure whether any noises which may be heard are produced by the galvanic current or not, and the person experimented on is not at all in a condition for making accurate observations; fortunately the auditory nerve can be stimulated in other and simpler ways, and best of all by a bifurcated or *divided* electrode, which can be applied to both ears at once. At a pinch a binaural stethoscope answers very well, small pads of moistened sponge being substituted for the ivory ear pieces; these ends may be introduced into the meatus, or may be applied just in front of the tragus and kept in place without unnecessary force by an elastic band or spring.[*] If a stethoscope is used, the lower portion can be removed, and the tubes closed up by small corks, the wire from the battery is clamped to the metal, and the other electrode may be applied to the sternum or back, or held in the hand. For experimental purposes it may be placed in a bowl of water, into which the hand can be dipped. One can then experiment comfortably upon oneself, using one hand to turn on the current and the other to make connection through the bowl of water; a commutator and a galvanometer should form part of the circuit. Both ears are then under exactly similar conditions of pole, and the extraneous noises from accidental movements of the electrode in the ears are reduced to a minimum. The current can be made, broken, increased, diminished or reversed with ease, and the effects noted and written down, and in this way alone can one hope to arrive at a satisfactory knowledge of the electrical reactions of the auditory nerve. The experiments are not very pleasant because the healthy nerve requires a considerable amount of current to stimulate it, perhaps as many as 12 or 15 cells (15 milliampères), and its effects on the optic nerve, on the brain, and on the skin under the electrodes, all force themselves into prominence.

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[*] Messrs. Arnold and Son have made a very convenient divided electrode for this purpose by converting the framework of a light binaural stethoscope.

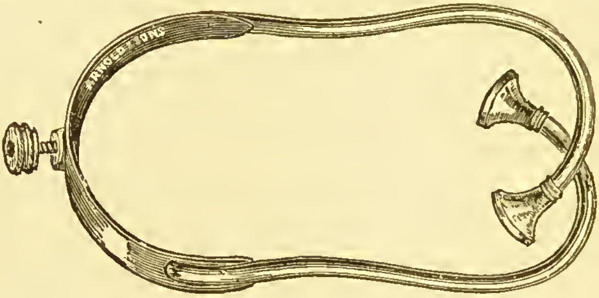

FIG. 75.—Divided electrode.

Galvanic hyperæsthesia of the auditory nerve is frequently met with in all sorts of ear disease, but it is not present in all cases of tinnitus, or subjective noises; when tinnitus and galvanic hyperæsthesia coexist the subjective noises are readily influenced and controlled by galvanism, and many brilliant cases of cure have been effected. If the tinnitus does not respond to galvanism it is much less likely to be benefited by electrical treatment (see also Tinnitus, Chapter XI.). The opposite condition to electrical hyperæsthesia, namely, electrical torpor of the auditory nerve, is also known.

CHAPTER IX.

GENERAL THERAPEUTICS.

Introductory. Effects of electricity. Choice of current, galvanism or faradism. Strength of current. Choice of pole. Methods. General faradisation. Other faradic methods. Galvano-faradisation. Galvanisation of the cervical sympathetic. Central galvanisation. Self treatment by patients. Electric belts.

174. **Introductory.**—The therapeutic methods employed with statical electricity have been already considered in the chapter dealing with statical apparatus. We have now to consider the methods of procedure with the constant galvanic current and with the interrupted current. In either case the treatment may be general or local. Of general methods the one most fully deserving the name is treatment by the electric bath (galvanic or faradic), which will be fully dealt with in the next chapter.

In commencing the study of electro-therapeutics the first questions to arise are the following:—(1) What results are to be expected from the treatment? (2) When should the constant current be used, and when the interrupted? (3) What is the proper strength of current and the proper duration of treatment? (4) What is to be the direction of the current and which pole is to be applied to the affected part? (5) What are the manipulations required?

175. **Effects of electrical treatment.**—The effects

produced by electrical treatment may be arranged thus:—

(a) Stimulating and tonic effects general and local; these belong to both galvanism and faradism, but especially to the latter, which acts as a stimulus, partly upon the contractile tissues, both directly and through their motor nerves, partly by its effect upon the sensory nerves, and partly in a reflex manner through the vasomotor system, producing increased vascular activity in the parts which it reaches. These effects are to a certain extent shared by other modes of stimulation, as for instance, by massage, by treatment with hot and cold douches followed by friction with rough towels, and so forth; but electricity has certain advantages over these other modes of stimulation, especially in paralytic affections, from its greater power of setting up muscular contractions, and from the ease with which it can be directed to any required parts.

The effects which peripheral stimulation exerts upon the central organs play an important part in electrical treatment, and afford the best explanation of the benefits which follow even in cases where the treatment has been applied to the peripheral parts only.

The stimulating effect of electrical treatment is perhaps nowhere better shown than in its immediate action in hysterical affections, for a single application of the faradic current to the throat for a few minutes will often entirely dispel hysterical aphonia and in hysterical paraplegia the anæsthesia and motor paralysis will frequently vanish altogether in the course of the first sitting.

(b) Electrotonic effects.—These have been already considered in § 142, and the physiological effects there described have been made the basis of much of the treatment by the continuous current. With the alternating currents of the induction coil electrotonic states

cannot be expected, but with constant currents the phenomena of electrotonus should be kept steadily before our minds in treatment, for they show us when the exciting action of the exalted irritability of kathelectrotonus is to be brought to bear upon a patient, as in paralyses; and when the calming effects of the diminished irritability of anelectrotonus are more desirable, as in the relief of painful affections.

It has been objected that the theory of electrotonus as applied to treatment is deceptive, owing to the impossibility of securing the effects of one pole, uncomplicated by those of the other (see § 145), and that electrotonus is only a temporary condition which disappears as soon as the circuit has been broken, but in spite of these objections we are compelled very often in default of any better guidance to follow the indications which are afforded by electrotonus. While admitting the theoretical truth of the first objection, we may say that the predominating effect at the point of application is that of the pole chosen, for instance, in the case illustrated (fig. 69) the virtual kathodes are far weaker than the actual anode.

(c) Electrolytic effects.—These, which are manifest chiefly at the surfaces in contact with the electrodes, are of use for the most part in the surgical departments of electrical treatment, and will be more fully considered in a chapter of their own. We are not yet able to say how far the trophic results of electrical treatment may depend upon the molecular interchanges set up or directed by galvanic currents, for we do not even know whether the interchanges are of no consequence or are of extreme importance.

(d) Trophic, Catalytic or Alterative effects.—*Erb* has suggested the hypothesis that a stimulation of trophic nerves

or of centres may be possible by the aid of electricity, saying. "It is probable that every nerve contains trophic fibres and is placed under the influence of trophic centres, upon which the electric stimulus may act, and so modify the nutrition of nerves, muscles and other organs, hastening regeneration and removing the more subtle nutritive disturbances." "We may assume that gymnastic and other methodical exercises influence the muscles by an excitation of the nutritive processes due to the calling into play of the trophic nerves under the stimulus of motor activity. Is it not possible in the same way to account for many of the curative results of electrisation by assuming a stimulation of the trophic processes."

(e) Osmotic effects.—(See §§ 153, 199).

176. **Choice of galvanism or faradism.**—Some indications for the choice of current will have been learnt from the last section; generally speaking it may be said that for stimulation pure and simple faradism is the best; faradism is of great value in paralysis of muscles if they are able to react to it, but if they present the reaction of degeneration then the constant current is the better. Fashion has much to do with determining the choice between the two modes of treatment.

Duchenne was a firm believer in the superiority of faradic treatment for all kinds of paralytic conditions, and *Remak* was as warm a supporter of the constant current. The former writer declared that he had met with far better results from faradism than galvanism. The latter was as confident of the superiority of his method.

Whatever benefits may be produced by electrolytic or electrotonic effects must be possessed by galvanism alone; the advantages of excitation, of trophic or catalytic effects, may be shared by both. At present the continuous current is most in favour, and, perhaps, rightly so, but until the rational treatment by electricity shall have overtaken the empirical, it is not always possible to give any better reasons for the preference, than that such and such a method has already shown itself to be useful.

177. **Strength of current.**—In determining the strength of current it is necessary to remember that but little benefit is likely to follow torture, and that no needless pain should be inflicted upon the patient. With faradism the operator must gauge the strength of his current upon himself first, and must repeat the test with every increase in its strength; a strict adherence to this rule is the best plan by far of ensuring the proper amount of caution. Patients as a rule are extremely intolerant of painful shocks, and it must be remembered that the very name of electricity is enough to make many patients at least a little anxious or alarmed on their first trial of the remedy; the strange look of the apparatus, with its gleaming knobs, the clicking or humming noises which it gives out, and above all the mysterious nature of electricity, combine to make every patient feel nervous, and the operator, himself quite familiar with his apparatus, is very likely to forget this. It is therefore wise for him always to assume an attitude of great carefulness in the management of his instruments, that he may not appear to his patient to be reckless in handling them.

With constant currents the galvanometer provides the means of regulating the dosage. For most forms of local treatment five milliampères is sufficient, and may be too much for children or sensitive or nervous people, at the commencement of a course of treatment; even this current must never be switched on or off abruptly, but only very gradually, the patient being carefully watched for any signs of pain or discomfort, the current collector (§ 125) must be properly made and tested from time to time to see that it allows of alterations in the number of cells without any breaks of circuit; when the applications are made to any part of the head or neck, additional care must be exercised, the effect upon the brain being very peculiar and unpleasant, especially at make and break. The only occasions when larger currents are required are in electrolysis of nævi, when a current up to 100 milliampères is sometimes required, and in *Dr. Inglis Parsons'* method of treating malignant tumours, in both of which an anæsthetic must be used, and in *Apostoli's* treatment. In the latter no anæsthetic is used, although the current may exceed 100 milliampères. Toleration of so large a current is rendered possible by the use of a very large electrode for the cutaneous surface to reduce the density of the current per unit of surface, and by the insensitiveness of the the uterus to which the other pole is applied.

The duration of each sitting may be on an average ten minutes, but here again the patient's feelings must be taken into account, and the time shortened or lengthened as may seem advisable in each particular case.

The number of sittings varies very much, usually a considerable number are required. It is best to tell the patient at the commencement that he must not expect magical and sudden cures, but rather a gradual slow improvement. In some cases of infantile paralysis it may be necessary to continue treatment for three, six or even twelve months. As a general rule it may be said that at least a month of treatment, with two or three sittings a week, is required to produce permanent benefit, but of course there are exceptions, and it is not possible to lay down any precise rules. It is usual for improvement to begin early if the treatment is likely to do good. In that case the patient will be encouraged to persevere. If at the end of a month of regular treatment there is no visible change, or if the improvement has ceased to be progressive, then the treatment may be discontinued.

178. **The choice of pole.**—With faradic alternate currents the influence of pole is reduced to a minimum, and the two electrodes may be considered to be of equal value ; with continuous currents there are well marked differences in the effects produced. From electrolysis the region of the anode or positive pole becomes acid, and in the treatment of nævi the needles which are negative become surrounded by a soft slippery material, alkaline in reaction, and they are likely to slip out and so break the circuit, unless carefully watched ; when a stricture of the urethra is to be electrolysed the negative pole is the one to be introduced ; accidents have followed neglect of this precaution ; the positive pole has been used and has become firmly adherent to the stricture, and laceration and bleeding have followed its forcible withdrawal.

The sedative effect of the anode (§ 142) determines its use in neuralgia, sciatica, spasm and tinnitus aurium, while the stimulating effect of the kathode and the greater ease with which it causes muscular contraction have determined the use of the negative pole in paralysis. It is not possible to generalise further about the choice of pole, but instructions will be found in the chapters on treatment.

A simple rule has been laid down for the direction of the flow of current in medical practice by *Remak*, who advises that the current should pass along the nerve fibres in the direction in which they conduct, namely, downwards to the periphery for treatment of motor affections, and upwards from the periphery for sensory affections.

Brenner prefers to consider that the direction of the current is of less importance than the influence of the poles; and we should therefore speak of the choice of pole rather than the choice of the direction of the current, because the current does not run in straight lines from anode to kathode; however, the distinction between direction of flow and choice of pole is after all a subtle one. To apply the kathode to the paralysed thumb muscles, the anode being at the nape of the neck, may reasonably be spoken of either as treatment by a descending current or as treatment by the negative pole. Those who object to speak of the influence of direction of current base their objections on the fact represented in fig. 69, that round a pole applied to any part of the surface of the body the flow of current is not in one but in every direction, and therefore there can be no definite direction of the flow in the muscle under treatment, the effects being effects of pole and not effects of direction of current. However, with the indifferent electrode central, and the active one peripheral, it is permissible to speak of treatment with descending currents when the active electrode is the kathode, and of ascending currents when it is the anode; the words ascending and descending having reference to the general direction from anode to kathode, and not implying any theory of the physiological or therapeutical importance of the direction of the flow at the seat of disease.

179. **Methods.**—Most electrical treatment is now carried out by using a single active electrode, and an

indifferent electrode. The size of the indifferent electrode is determined by the current to be used; the ordinary size of the tin plate electrode (fig. 56) is 4½ inches by 2½; but for treating nævi by the unipolar method it must have three or four times that surface. The active electrode may be three, four, or five centimetres in diameter according to the extent of surface to be included in the treatment; the electrodes must be moistened, best with warm water, the indifferent one in its sheath is then pushed down the back of the neck for patients who are dressed and sitting up, or it is placed under the sacrum or buttocks for patients lying down. The part to be treated is then bathed with warm water, and the active electrode applied, and the current slowly raised to three, four, or five milliampères. The active electrode is to be moved slowly over the whole of the affected part (*labile* method) or kept still in one place (*stabile* method). The current may be closed and opened for the sake of producing muscular contractions, or may be even reversed by means of a commutator, for the same purpose. These reversals, "voltaic alternatives" (*alternatives voltianes*), are especially powerful in exciting muscular contraction.

It is often advisable with faradism, seeing that there is then no question of choice of pole, to have the indifferent electrode also in the neighbourhood of the part under treatment; by doing this the sensations produced can be limited to the parts affected, and they will appear to the patient more tolerable than when a faradization of the muscles of a limb is attended by pain or discomfort in a remote and healthy part of the body as well.

In treating the muscles of the hand for instance, it is often quite convenient to lay the indifferent electrode under the palm while the dorsum is being treated, and *vice versâ*.

180. **General faradization.**—We can now consider the methods of general treatment. The old plan of faradizing patients by means of metallic electrodes held in the two hands may be regarded as a rude attempt at general faradism. *Drs. Beard* and *Rockwell* have elaborated a method of general faradization, the advantages of which they claim to have been the first to bring before the notice of the medical profession.

The object aimed at is "to bring every portion of the body in turn under the influence of the faradic treatment so far as is possible by external applications."

They consider that this is best accomplished by placing one pole under the feet or over the sacrum, while the other is moved over the general body surface. The patient should stand or sit with both feet resting on the surface of a large metal electrode covered with moist flannel; this must be kept warm by means of a hot water bottle or some other contrivance, as the treatment lasts for from ten to twenty minutes. The other, active, electrode is then to be moved over the various parts of the body, two or three minutes being given to each of the more important regions in order as follows.

To the head (forehead and vertex) ...	1	minute.
,, neck and cervical spine ...	4	,,
,, back	3	,,
,, abdomen	3	,,
,, arms	2	,,
,, legs	2	,,

The application to the limbs is less important, and may be omitted in certain cases.

The active electrode should consist of a metal disc or ball covered over by a large sponge of six inches in diameter, and kept moist with hot water. The object of using electrodes of large size is that by their means the current is rendered less painful, and consequently the patient can bear stronger applications; the use of the operator's hand as the active electrode* is also recommended by *Dr. Beard* for the following reasons, viz., in certain cases it is more agreeable to the patient from its softness and pliability; and its tactile sensibility makes it easy for the operator to gauge both the amount of pressure he is employing, and also the force of the current used. When one hand is to be used as the active electrode the operator should put himself in the circuit by holding the wet sponge in his other hand, the current then passes through his own body from hand to hand. He can thus readily vary the force of the current by altering the degree of pressure with which he holds the sponge, for when it is firmly grasped the current passes more readily and is increased, and when the grasp is relaxed the current is diminished; no bad results follow to the operator, on the contrary he shares with his patient the benefits of the treatment, and considerable development of the muscles of the arms is sai to follow.

The patient may be seated while the upper part of the body is under treatment, but should stand up if possible for the application to the hips and thighs. A loose garment like a shirt or night-gown can be worn, or a large shawl or blanket may be thrown round the patient. The electrode can then easily be manipulated and moved over the surface of the body without exposure.

In the region of the head the forehead and the vertex are the most important; if the hair is at all long or thick it may be moistened, to diminish its resistance. The treatment of the back of the neck and the whole region of the spine is considered to be extremely important and should be thoroughly carried out, the electrode being slowly moved up and down along the whole length of the back.

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* This mode of application is spoken of as the "electric hand," or the "hand electrode." It was employed by *Duchenne.*

The sensations felt by the patient should be of an agreeable nature, a pleasant thrill, without any sort of pain or discomfort. The operator must bear in mind that the sensibility of the surface varies in different parts of the body and he must adapt the force of the current to suit such variations, using the hand by preference for treating those parts which are most sensitive.

The results of the treatment by general faradization are mainly tonic in their nature, a feeling of vigour follows, depression or fatigue are relieved, the appetite is increased, the patient sleeps more soundly, there is an increase in the firmness of the muscles, and an improvement in the circulation. In some patients these results follow promptly, in others their development is more gradual; the same variability in the response of patients to other forms of electrical treatment has been observed by others.*

The treatment by general faradization should be carried out two or three times a week, or every other day. Currents sufficiently strong to cause muscular contraction should be employed, as soon as the patient has become accustomed to the treatment and is able to bear them without apprehension.†

* "There are some people in whom the electrical current is poweful for good or for evil, while others again are but little affected by it."—*Erb.*

† For a full account of general faradization, with figures, the reader should consult "Medical and Surgical Uses of Electricity."—*Beard and Rockwell.* H. K. Lewis.

181. **Other faradic methods.**—But little can be said on the subject of the kind of coil best suited for medical treatment; we have already (§ 120) briefly alluded to the differences between primary and secondary induced currents; and differences of degree also exist in secondary coils of different make, according to the number of turns and the thickness of the secondary wire. After carefully comparing the effects produced by two secondary coils, one of many turns of thin wire, and the other of few turns of thicker wire, both being alternately placed round the same primary coil, we are not able to perceive any difference in the sensory effects of the two coils with currents just strong enough to cause muscular contraction, while with stronger currents both coils seem to yield equally painful shocks.

There is also no appreciable difference between the two poles of a medical induction coil. It is true that with large Ruhmkorff coils the character of the spark differs at the two terminals of the secondary wire, but in those powerful coils the difference between the make and break currents is accentuated by the presence of a condenser in such a way that the spark consists almost entirely of a series of breaking currents passing in one direction. As there is no condenser to ordinary medical coils, and no air gap is present in its application to the human body, the shocks of an induction apparatus are best regarded as an alternate passage of currents in both directions, those in one direction being rather more sudden and of rather higher electromotive force than are those in the other.

In considering the question of the influence of the poles in galvanic treatment, it will be found that our stock of knowledge of the subject is at best only a very slender one, certainly it is not enough to justify any confident statements upon the relative values of the poles of a secondary circuit.

When sensory impressions are chiefly desired, the dry skin is faradised with a metallic brush of very fine wires, and the current employed must be more powerful than for muscular stimulation, here again the difference between short and long coils is inappreciable, the required cutaneous effects can be produced as well with a short thick secondary coil as with a long one of thin wire.

The faradic current is to be employed where tonic or stimulating effects are chiefly desired, and with this object it is valuable in the treatment of paralysis, of anæsthesia, or in conditions where the involuntary muscles require to be roused; thus the abdomen and the rectum may be faradised for constipation, and the bladder or the uterus for atonic conditions.

In the treatment of paralysed or wasted muscles faradism has been employed systematically since the time of *Duchenne*, and even before his time it had gained a considerable degree of popularity. The paralysed muscles can be faradised directly by the application of the active electrode over their surfaces or indirectly by its application to their motor nerves; in either way similar results are obtained.

Reference to the chapter on diagnosis explains the methods of exciting the individual muscles and nerve trunks, and the treatment consists simply in moving the wet surface of the electrode slowly over the moistened skin covering the muscles with a sliding and a rolling movement. This sliding movement is a guide to the proper degree of moisture necessary. If either the skin or the surface of the electrode be too dry the latter will not slip smoothly, but will seem to stick, or move harshly.

When this is felt the electrode must be moistened afresh.

It must not be assumed that the degree of benefit from faradism can be measured by the amount of visible contraction of the muscles under treatment, for in addition to the exercise so produced there are vaso-motor effects, and reflex effects through the centres in the cord, both of which take part in bringing about the final results.

The duration of each application in local faradism should be about ten minutes, and this time must be distributed over the muscles or other parts needing treatment. When the dry brush and painful currents are employed, five minutes will usually be quite long enough, and the patient must on no account be reduced to a state of exhaustion from over-treatment. The operator should always try the current by experiment on his own muscles, in order to know exactly what amount of discomfort or pain his patient is called upon to bear.

182. **Galvano-faradization.**—*Dr. De Watteville* has recommended the simultaneous use of the continuous and the interrupted currents under the above name. The method consists in "uniting the secondary induction coil and the galvanic battery in one circuit by connecting with a wire the negative pole of the one with the positive of the other, attaching the electrodes to the two extreme poles and sending both currents together through the body," we are told that "the effects of the faradic current are greatly enhanced by a simultaneous galvanization, because the points upon which the stimulus falls are in a state of exalted excitability or kathelectrotonus. Owing to the "refreshing" properties of the galvanic current upon muscle, the fatigue and exhaustion which might otherwise be the consequence of

energetic faradization are avoided." *Dr. De Watteville* has a very high opinion of the advantage of this mode of treatment, particularly for electrization of the abdominal viscera, and in rheumatic conditions, and in atrophic paralyses.

The strength of each component may be about the same as when either is being used alone.

183. **Galvanization of the cervical sympathetic.**—A good deal has been written of this proceeding, but as *Dr. De Watteville* has pointed out in an entertaining and caustic article in "Brain,"* it is extremely doubtful whether the cervical sympathetic has ever been appreciably influenced by electrical treatment. At least none of the ordinary physiological effects of stimulation of the sympathetic are produced on the pupil or the blood vessels of the head and neck; the treatment is carried out by placing one electrode below the ear and the other at the nape of the neck and passing a weak current. All sorts of advantages have been claimed for this method, which has become an established part of the routine treatment of many morbid states of the central nervous system, so that in *Erb's* opinion it should be carried out "in every case where it is hoped to act on the circulation and nutrition of certain parts of the brain." *Dr. Moritz Meyer's* plan is to place a medium sized electrode at the angle of the jaw, with its surface directed backwards and upwards towards the vertebral column. The other pole should be larger, and applied to the opposite side of the back of the neck, on a level with the fifth, sixth or seventh cervical vertebra. The kathode is usually placed in front, but not always; the current should be two to five milliampères, and the duration

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* An electrotherapeutical superstition. "Brain," iv., 1881, p. 207. *A. De Watteville.*

one to three minutes, the application *stabile.* In certain cases both sides may be treated successively. As this treatment must involve all the other important nervous parts of the neck and the base of the skull, as well as the cervical sympathetic, it would be better to adopt *Dr. De Watteville's* suggestion, and speak of *subaural galvanization*, rather than of galvanization of the sympathetic.

184. **Central galvanization.**—This is a plan of applying electrical currents to the nerve centres, also introduced by *Drs. Beard* and *Rockwell.* It consists "in placing the negative pole at the epigastrium, while the positive pole is applied to certain parts of the head (chiefly the vertex), to the sympathetic and pneumogastric in the neck, and down the whole length of the spine from the first to the last vertebra." It is said to be useful in cases of hysteria, neurasthenia, sleeplessness, dyspepsia, and other complaints. The duration of the treatment may be about ten minutes, the position of the negative pole must be changed from time to time, to prevent any bad electrolytic effects upon the surface of the skin beneath it. The strength of current should be varied between five and ten milliampères, according to the part under treatment.

For the application of continuous currents to the skull three methods have been proposed, the longitudinal, the transverse and the oblique. In the first the electrodes are applied to the forehead and occiput, in the second they are placed either on the two sides of the frontal bone, or on the mastoid processes, in the last they are applied to the forehead on one side and the nape of the neck. The third method is considered specially useful, because the current then follows the direction of the motor fibres from the cortex to the anterior pyramids of the medulla. The anode is usually placed in front. In all three methods it is recommended to use large electrodes and weak currents very gradually increased, and the duration of a sitting should not exceed five minutes.

185. **Self-treatment by patients.**—It is a matter of the greatest importance that all electrical treatment should be carried out by the medical man himself whenever this is possible, and if it is not possible for him to do so then at least he should supervise the treatment as often as he can. When patients are left to themselves with a battery the results are uniformly unsatisfactory, and the usual consequence is solely to bring electrical treatment into undeserved discredit. It would be very nearly as reasonable for a patient to attempt to act as his own dentist as for him to try to cure himself by means of a battery without full medical advice and constant supervision. Only those who use batteries regularly are able to deal with the difficulties of making them work properly, and it is therefore absurd to place one in the hands of a patient who cannot even know whether it be working properly or not.

186. **Electric belts.**—It is necessary to say a few words on the subject of the so-called electric belts. These things occupy a prominent position in the "jugglery of advertising quacks," and medical men are frequently called on by their patients to give some advice or opinion about them. For the most part they consist of pieces of zinc and copper more or less fantastically joined together, and sewn into a leather belt; here and there the pieces of metal project so that they can come into contact with the body surface.

It is quite possible that minute currents may be set up by the moisture of the skin acting upon the metal pieces of the belt; evidence that this is so is indeed afforded by the fact that soreness and ulceration is sometimes produced at the points where the bare metal touches the skin, but it is difficult to see what possible good result can follow so far as the wearer's general health is concerned. From what we have already said of the uselessness of patients treating themselves at all by electricity it follows *a fortiori* that the indiscriminate buying and wearing of electric belts is a futile proceeding, even supposing (which is not often the case) that they are designed in a proper manner to yield a current. At the present time the number of persons who wish to buy or have bought an electric belt is considerable, and on this account it is important for medical practitioners to have some knowledge of their plan of construction and properties in order to be able to make use of reasonable arguments in pointing out their real worthlessness. The small minority of patients who profess themselves cured by the wearing of electric belts are people of that class in which the effect of the imagination, or the influence of what is now-a-days known as self-suggestion is most active; for them the name of electricity has always had and will continue to have miraculous powers, to the neglect of reason and common sense.

CHAPTER X.

THE ELECTRIC BATH.*

The bath. Accessory apparatus. The galvanic bath. The faradic bath. The galvano-faradic bath. Hot air or vapour electric bath. Uses in chronic rheumatoid arthritis. Gonorrhœal rheumatism. Gout. Lateral sclerosis. Metallic poisoning. Tremors. The introduction of medicinal substances into the body. Raynaud's disease. Sciatica and lumbago. General conclusions.

187. **The bath.**—The electric bath is used in the treatment of morbid conditions which affect the whole constitution, and especially in some of those which have their origin in the central nervous system. It is the most thorough way of applying general faradization or general galvanization. It is rather an extravagant and wasteful way of applying the continuous current except in such conditions as those alluded to, in which the general system suffers and when there is no local manifestation of the disease on which the effects of the current can be concentrated. Galvano-faradization can also be conveniently applied through the medium of the bath when desired, but we have not found it better than the use of either galvanism or faradism alone. In lead palsy the interrupted current may be used singly to the extensor muscles of the wrist and fingers after the galvanic bath is concluded.

The bath itself may be made of polished metal, of porcelain, or of wood; but porcelain is by far the best material for the purpose. When made of metal the bath forms one of the electrodes (passive electrode) one pole of the battery being attached to it. Such baths are usually made of copper and are kept quite bright. A japanned metal bath is not suitable for any form of electric bath, because the japanning is never so perfect as to insulate it completely, while it also does not allow the bath itself to act as an electrode in the way described for the bright metal bath. When the copper bath is used provision has to be made so that the patient may not touch the metal. The bottom of the bath is covered by a wooden lattice work on which the patient lies, a rest is also provided for the back, and projecting pieces of wood are placed at the sides, at the level of the hips, so as to prevent the body of the patient from touching the sides of the bath. This form of bath is of little use except for general faradism, or it may be employed to influence any particular region of the body by a moveable active electrode used locally on different parts of the body, and the part that it is applied to has for the time being to be out of the water. In this way such strong currents cannot be borne as when the whole of the body is immersed, for although the current is widely diffused in its passage and enters the body at many points, yet it will be concentrated at the part to which the second electrode is applied, and therefore a stronger current than 10 or 15 milliampères cannot be tolerated. It is far better to employ a bath made of a non-conducting material such as porcelain or wood. A porcelain bath is the cleanest and best, but it is also the most expensive and is very heavy. Each porcelain bath is made in a mould and many are rejected after firing on account of some flaw; this, and the risk of breakage, makes them expensive. A wooden tub is therefore sometimes used for the sake of cheapness, and the best wood of which it can be made is oak. Its appearance can be improved by having the outside polished and its hoops of iron painted black. The inside of all wooden baths used for electrical purposes should be carefully painted with non-metallic paint. White non-metallic enamel is the best for this purpose. If the inside of the bath is not thus protected the wood in time becomes waterlogged. It is then a conductor of electricity, and is almost useless for the purpose of the electric bath.

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* This chapter is a reprint, with a few alterations, of Dr. Steavenson's papers in "The Lancet," 1891, vol. i.

The water in the bath should be of the temperature of 100° F., but it is often advisable to give the first bath of a series at a temperature of 98°, for many patients cannot at any time bear a higher temperature. The bath should be well filled with water so that when the patient lies in it the whole body and the shoulders may be covered. A bath thermometer must always be used to ascertain and regulate the temperature.

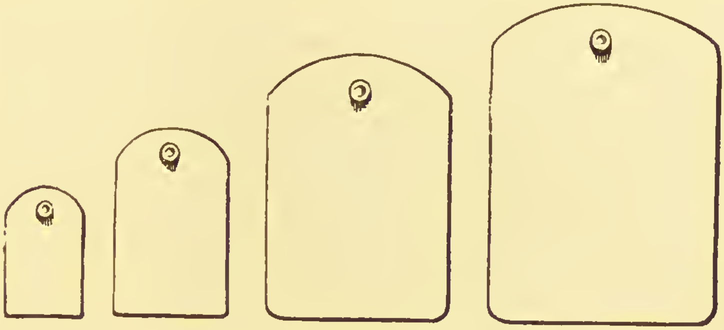

FIG. 76.—Electrodes for the bath.

188. **The apparatus required.**—Ordinarily the electrodes are metal plates placed at the head and foot, they should always be kept clean and bright. These metal plates are provided with binding screws to which the battery wires are attached (fig. 76). The best metal

is copper or nickel. It is no use having these metal sheets plated, as is sometimes done for appearance sake, for the plating quickly leaves the positive pole. The electrode placed at the head of the bath is usually the larger, and may measure eighteen inches by twelve, that at the lower end of the bath being eleven inches by nine. Smaller plates are sometimes used for the hips and knees when it is wished to localise the current more or less at those parts. The water should always be deep enough in the bath to cover the plates.

The shoulders and back of the patient are kept from touching the plate at the head of the bath by a rest made of wood, something like a picture frame having pieces of webbing stretched across (fig. 77). The light wicker fire screens which are made to fit on to the backs of chairs are very convenient and comfortable for protecting the patient's back from touching the metal plate.

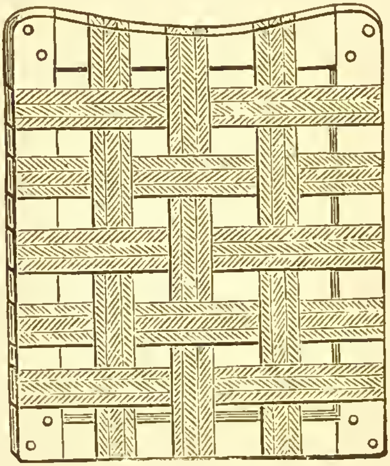

FIG. 77.—Back rest.

A depression is made in the upper bar of the frame to support the back of the patient's head. The feet may be allowed to touch the electrode at the opposite end of the bath because the epidermis on the soles is thick enough to take care of itself. If a patient prefers it, the feet need not be placed in actual contact with the metal, but they should be kept in close proximity to it. A part only of the total current in circuit traverses the body, the remainder passing through the water in which it is immersed, the body is the better conductor of the two, though not greatly so. The water in the bath offers a broad conducting medium with a large transverse sectional area, several times larger than the patient and therefore a considerable part of the current traverses the water and is altogether lost to the patient.* This makes the employment of electricity in the form of a galvanic bath a wasteful one. It has been calculated that an eighth part only of the current traverses the patient. Thus with a current of 200 milliampères passing through the bath the patient's body carries about 25 only. It can easily be shown that part of the current traverses the human body when immersed in a bath, even if the feet do not touch the bottom electrode, for if one of the legs is held up out of the water and so removed from the circuit, the current as registered by the galvanometer is immediately reduced. By dipping both hands into the bath at some distance apart the galvanic current passing in the water can be easily felt, for a certain portion of it then passes through the new channel offered to it, going up one arm and down the other. With the faradic current the effect is such that the wrists are quite doubled up by the contraction of the muscles when the hands are held far apart. If salt or acid is added to the bath, the water becomes a better conductor than before, and the patient's share of the total current passing will be reduced. It is therefore useless and objectionable to make such additions to the water. In spite of this fact, many books have advised it to be done. In the treatment of a case the current should be allowed to flow through the patient for from ten to fifteen minutes. It is often not possible to detect much improvement in a patient's condition until after the sixth or eighth bath. The first five or six baths may be given on consecutive days, and then every other day until the end of the course. A course may consist of thirteen or fourteen baths. A patient may have more if he wishes, and if he is continuing to progress; but often after a course is over the patient's condition will continue to show improvement after the baths have been left off, and the improvement will be kept up unless some fresh cause arises to bring about a relapse.

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* The resistance of the bath when the patient is in it is about 120 ohms; but varies with the quantity of water used.

The current to be employed in a galvanic bath must be very gradually raised until the galvanometer registers 200 milliampères, of which the patient really gets a current of about 40 milliampères; but it is best for the first few baths to use a current of 60 or 100 milliampères only. A battery of large Leclanché cells answers very well, sixty of these may be connected with a switch board having a double or single collector (§ 125) and a commutator (§ 126); and a galvanometer graduated to read up to 250 milliampères must be included in the circuit. An induction apparatus is also required, it must be powerful, and should be so arranged that it can be easily set in action, regulated, and switched in or out of circuit.

A Stöhrer's battery may also be used (§ 112), but they are rather uncertain, largely through faulty contacts at the upper part of the carbon plates, they also need more attention than Leclanché cells.

189. **The galvanic bath.**—The patient after entering the bath should be allowed a few minutes to recover from the reaction produced by the warm water before the current is turned on. The current should be increased slowly and cautiously, and the galvanometer watched, and at the termination of the bath the current must be reduced as slowly. The direction of flow should generally be from the feet to the head, the kathode being at the upper end of the bath, and the anode at its foot. A medical man should always be present to regulate, increase, or diminish the strength of the current. The patient can wear an ordinary bathing costume. With female patients the presence of a nurse or a maid is necessary, but the medical man should also remain in the bath-room while the current is flowing. An arrangement is needed on the switch board, or on the battery, for completing the circuit and for gradually increasing the strength of the current without any interruptions taking place, so that all chance of giving a patient a shock is avoided. With the large currents used this is most important. As the current is slowly augmented the first sensation experienced by the patient is usually a slight pricking or tingling at the ankles or at the knees. A galvanic taste may be perceived as the current becomes stronger. Should the patient's head feel full or throbbing during the administration of the bath a cold wet towel may be placed on the top of the head. And if any faintness is caused, the current must be reduced. An electric bath must not be taken too soon after a full meal. During the bath the pulse rate is said to be diminished, as are also the respirations. After the bath the skin of the back

near to the upper electrode will be found of a bright red hue, this will gradually pass off in an hour or two. After dressing, the patient should rest for fifteen or twenty minutes before going out into the open air, and should not immediately engage in exhausting exercise. After an electric bath there appears to be no particular tendency to catch cold and the patient generally feels exhilarated and better. Should there be any sign of languor or depression after a bath the treatment should not be persevered in.

190. **The faradic bath.**—When the interrupted current is used either the primary or the secondary coil may be employed. Special faradic coils of large size are best for use with the bath. There must be some means of regulating the strength of the primary current either by moving or shielding (§ 119) the core of soft iron wires in its centre; or by a rheostat (§ 130).

The current from the secondary coil can be regulated by the amount of the coil that is allowed to encircle the primary one. It is always best in the faradic apparatus to have the secondary coil after the Du Bois-Reymond sledge principle, that is, wound upon a separate bobbin, and capable of sliding over the primary (figs. 47, 48).

191. **The galvano-faradic bath.**—Treatment by the combined currents—constant and interrupted—can also be very conveniently carried out by means of the bath. The two currents are passed along the same wire; the terminals of the secondary coil being connected to the bath electrodes, which are also carrying the galvanic current. The faradic bath is specially indicated in those cases of general debility which are suited to general faradization (§ 180) for which this treatment can often be substituted with advantage. The effect is decidedly invigorating; we have also

obtained good results in cases of post-hemiplegic weakness, in chronic myelitis, and in exophthalmic goitre, and both currents can be felt in the bath. The constant current of the full strength of 200 milliampères may be used at the same time with a strong current from the coil, which is worked from a separate battery.

192. **Hot air or vapour electric bath.**—In America electricity has been applied to patients when in a hot air or vapour bath. This form of application is said to possess certain therapeutical advantages. Patients who suffer depression and are in other ways unable to take the water electric bath can often bear the hot air or vapour electric bath. The bath is given in a cabinet constructed for the purpose. There is a stool connected to one pole on which the patient is seated, his head being outside of the box or cabinet. The other pole of the battery can be connected either with the floor of the cabinet, which is lined with zinc, or with special electrodes to be applied to different parts of the body. The cabinet contains a hot water coil which is connected with a boiler and heating apparatus outside.

The patient being seated on the stool the hot air or steam is admitted into the cabinet. The vapour is used at a temperature of 90° to 100° F. It produces perspiration and is used for chronic rheumatism, stiffness of the joints, and skin diseases. It is also used at a higher temperature when employed for internal congestions. The vapour bath cannot be borne at such a high temperature or for so long a time as the hot air, 106° to 110° F. is the usual limit, but the hot air can be borne up to 130°. The neck is surrounded by dry warm towels to prevent the escape of the heat. There are holes with doors in the side of the cabinet through which the medical man can pass his hands for the purpose of adjusting the electrodes to that part of the patient's body it is wished to treat. Sometimes a projecting metal arm is used with the end covered by sponge against which the patient's back or epigastrium can rest. This projecting arm is fixed to the back or side of the cabinet and is connected with one of the poles of the battery.

A hot air or vapour electric bath occupies fifteen or twenty minutes. At the conclusion the patient should be cooled down by a shower bath; a common watering pot may be used for this purpose. A drain pipe is connected with the bottom of the bath to carry off the moisture. Although the patient is enveloped with hot air or vapour the current can only be conveyed to him by contact of the electrodes. We made a series of experiments at St. Bartholomew's Hospital some years ago to see if a current could be conducted by spray. Pure water and salt and water were used and forced out of a metal nozzle connected with one pole of a battery, the jet was directed on to a metal receiver connected with the other pole and a delicate galvanometer included in what would have been the circuit had the vapour conducted any current, but we could produce no deflection of the needle. A hot air or vapour electric bath is therefore nothing more than the application of electricity to a patient whose skin is rendered a better conductor through the warmth and perspiration that is induced. The skin is softened and so rendered a better conductor. The vapour bath is more relaxing and soothing than the hot air bath.

193. **Chronic rheumatoid arthritis.**—The affection for which the continuous current electric bath is most useful is chronic rheumatoid arthritis, a most obstinate complaint that usually resists all forms of treatment. Electric baths will not cure inveterate cases,

but they will do very much to arrest the progress of the disease, to reduce the pain and swelling of the joints, and otherwise to produce amelioration in the symptoms. The natural tendency of the disease is almost always from bad to worse, but even in the worst cases persistent treatment with the electric bath combined with passive movements will result in some improvement. When the stress of the complaint has fallen on the hands and they have become distorted and useless, besides the plates already described as used for electrodes in the bath, a series of metal handles of different sizes (fig. 78) covered with house-flannel have been employed, and by their means the hands have gradually been opened out. Small handles are used at first and gradually increased in size as the patient's hand is able to receive them.

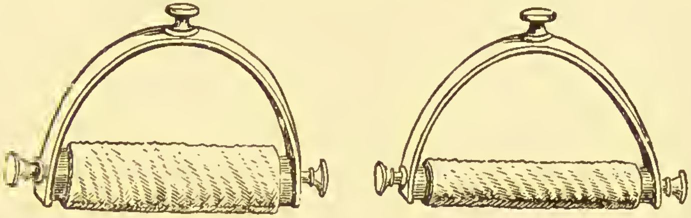

FIG. 78.—Handles for rheumatoid arthritis.

The handles are attached to the negative pole of the battery, and take the place of the foot plate. The current then enters the body at the spine and leaves it by the hand which grasps the handle, and it is thus concentrated upon the arms and hands. But this local application of the current should only be used for about the last five minutes of the bath; it should never altogether take the place of the general bath, which probably influences the whole system. The hands may also be made to grasp a metal bar supported across the bath and covered with moistened house flannel* (fig. 79).

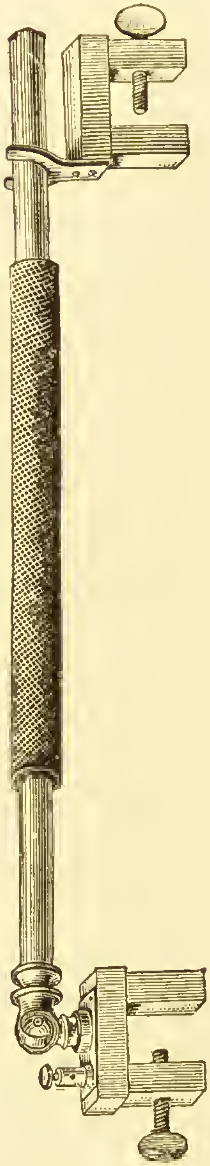

Fig. 79.—Bar electrode.

In this position the hands are raised out of the water and carry more current, and the entire current flowing through the bath must be reduced to suit the altered conditions. When concentrated in this manner on the hands the patient cannot bear more than ten or twelve milliampères. When changes in the direction of the current are to be made, the current must first be reduced to zero and then increased again. If the current were broken or reversed, the patient would receive a very unpleasant shock, even though the current were only 20 milliampères.

After the completion of a course of baths it is generally possible to notice some improvement in the condition of the patient. A patient for instance who could only climb upstairs slowly and painfully becomes able to make the ascent without assistance; or a woman who before could not hold her needle at all finds that she is able to use it slowly. The direction of the current in the treatment of rheumatic affections should be with the positive pole at the head of the bath.

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* *Ross*, "Diseases of the Nervous System," vol. i., p. 326.

When the larger joints such as the knees, hips or shoulders are the seat of rheumatoid arthritis, the current can be localised by the use of the smaller metal plates (fig. 76), one being placed on either side of the bath so as to include the affected joints between them. The joints should be afterwards subjected to rubbing and passive movements. Local arm baths or foot baths are sometimes given when one limb or joint only is affected. A porcelain or small wooden bath is the best, and two small metal plates attached to the respective poles of a battery are placed one on either side of the affected member and a current allowed to pass. Sometimes one electrode only is placed in the water, the other (a disc electrode attached to the negative pole) being applied to the affected joint or limb; for instance, to a rheumatic knee or to the arm in a case of cervico-brachial neuralgia. But ordinary galvanism without the intervention of a bath seems to be more suitable for these localised affections.

194. **Gonorrhœal rheumatism.**—This affection has also been treated by electric baths on the same plan as that followed in the treatment of rheumatoid arthritis but not with quite such satisfactory results. The positive pole is placed at the head of the bath. It is advisable to employ passive movements for the affected limbs after the bath.

195. **Gout.**—The galvanic bath is wonderfully efficacious in gout more especially in old standing and chronic cases. It has been suggested that it acts in part by eliminating the urate of soda through an electrolytic action, but the proof of this is still wanting. It improves the condition of the joints and

should be used after the acute attacks have passed off.

196. **Lateral sclerosis.**—This is another affection that appears to be greatly benefited by electric baths. The bath is given in the way already described for giving a general galvanic bath. The direction of the current in the treatment of lateral sclerosis should be with the anode placed at the head of the bath, so that the current enters the spinal cord between the shoulders. The electric bath certainly reduces the tendency to increased reflex excitability, for under this treatment the spastic gait is improved and the tendency to tonic spasm in the limbs is lessened. Early experience led to the belief that those cases of spastic rigidity, accompanied by severe tremblings and sudden contractions of the limbs in bed, were more amenable to treatment when they were the result of direct injury to the spinal cord; but latterly cases both of primary lateral sclerosis and of descending irritative lesions of the lateral columns, consecutive to cerebral disease, have also been found to improve greatly by this treatment. We have used both the faradic and the galvanic bath, and have seen more improvement follow the first of these methods of treatment.

197. **Metallic poisoning, plumbism, &c.**—A method of removing poisonous metals from the body by means of an electro-chemical bath has been employed. The method was introduced by *Vergnés** of

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* He had a bad ulceration on his hand produced by handling metallic solutions in the process of electro-plating. He connected his hand with the positive pole of a battery and placed it in a bath and immersed in the bath a metal plate connected with the negative pole. After a current of electricity had been flowing for fifteen minutes he found that the negative plate had on it a thin film of gold and silver. He repeated this hand electric bath a few times and found that his ulcer healed ! !

Havannah. For the removal of metallic impurities from the body it has been recommended to use a copper bath to which is attached the negative pole of a battery, the patient holding out of the water a handle covered with house flannel (fig. 78) first in one hand and then in the other for eight or ten minutes; or he may grasp the metal rod (fig. 79); but it cannot be allowed to rest on the sides of the copper bath, it must have some special insulated supports and be connected with the positive pole. When the metal to be removed from the body is lead, the water in the bath should be acidulated with sulphuric acid; for other metals nitric acid may be used. Instead of a copper bath a porcelain bath may be used with a large sheet of copper immersed in the water and connected with the negative pole. The current enters the patient's arm, passes through his body and so reaches the kathode, taking with it the metal and depositing it on the surface of the copper plate. Some of the metal is also said to remain in the water.

198. **Tremors.**—The tremors of mercurial poisoning can be successfully treated in this way, as many as five-and-twenty baths have been required to produce a cure. Alcoholic tremors can often be cured by six or eight baths.

199. **Cataphoric medication.**—The introduction of medicinal substances into the body has been recently revived by *Dr. Cagney* of St. Mary's Hospital.* The system was advocated and practised by *Vergnés* in 1855. He employed phosphate of iron and nitric acid. The patient was made to sit in a bath containing a solution of one of these substances while holding the negative pole out of the water. The current was passed through

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* "Brit. Med. Jour.," November, 1889.

the water into the patient and out at the arms, in its passage it carries some of the substance in solution into the patient. *Drs. Beard* and *Rockwell*[*] say, that there is little question that the passage of the current through the body, immersed in certain medicated solutions, aids in the absorption of some portion of the compound. Weakly and anæmic patients might in this way be made to absorb phosphate of iron. *Dr. Cagney* in his recent paper referred to the experiments of *Von Bruns* and *Hermann Munk*.[†] A saturated solution of the substances experimented with was placed in two of *Dubois's* conducting tubes, and the tubes were closed with clay soaked in the solution, they were then applied to the part of the body it was especially wished to influence. The direction of the current was reversed every five or six minutes. If the current is continued long in the same direction the absorption or osmosis is retarded through polarization in the tissues. It is therefore necessary to charge both electrodes with the solution to be introduced. The current should be fairly strong and kept flowing for from fifteen to forty-five minutes. A considerable quantity of a drug can be administered by this means; traces have been discovered in the saliva and urine for several hours afterwards.

The drug which gives the best results when administered in this way is the iodide of potassium, and when only one charged electrode can be used it should be attached to the negative pole, because the iodine is electro-negative and has a tendency to travel towards the positive pole. It is claimed that iodine can be effectively introduced in this way in goitre or strumous glands. It has also been used in cases of labyrinthine deafness and in lead palsy, also in syphilitic gummata and in diseases of the skin. Iodide of potassium may be tried in this way when it disagrees with the stomach, and the effects of the iodine can be more distinctly localised (see also § 153).

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[*] "Medical and Surgical Uses of Electricity," 8th edit., p. 768.

[†] *Erb's* "Electro-therapeutics," translated by *Dr. De Watteville*, p. 127.

200. **Raynaud's disease.**—The electric bath is most useful in all cases of defective circulation, including those cases of local asphyxia described as *Raynaud's disease*, in which the extremities often become blue and are very liable to chilblains, and sometimes even become gangrenous. The continuous current should be employed in the manner already described. The patient's general nutrition and circulation will be found to have improved at the end of a course, and the tendency to chilblains lessened. The complete bath is the best, but *Dr. Thomas Barlow* in his appendix to the translation of *Raynaud's* two " Essays on Local Asphyxia,"* recommends local arm electric baths, in the following words :—" The use of the constant current as recommended by *Raynaud*, has been adopted with advantage by several observers in cases of local asphyxia. The method which has been found most satisfactory by the translator in four separate cases has been the following :—immerse the extremity of the limb which is the subject of local asphyxia in a large basin containing salt and water ; place one pole of a constant current battery on the upper part of the limb and the other in the basin, thus converting the salt and water into an electrode. Employ as many elements as the patient can comfortably bear, make and break at frequent intervals so as to get repeated moderate contractions of the limb. In a typical paroxysmal case, if the two limbs are similarly affected, it will be

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* New Sydenham Society, " Selected Monographs."

found that the limb which is subjected to the above treatment will more rapidly recover than the one which is simply kept warm. It will also generally be found that the patient can tolerate the above mode of stimulation much more readily than he can bear friction with the hand, and that the use of galvanism in the way indicated, or by simply "painting" with two sponge electrodes, held on the limb at a short distance from each other, will so far diminish the pain that the patient becomes able to bear shampooing afterwards."

In chronic cases, although the relief is not so obvious, there can be no doubt at times as to the value of this measure in improving the nutrition of the limb, and in keeping the threatened gangrene at bay. Even when gangrene in the limited form which *Raynaud* describes, has supervened, galvanism to the parts above and around may be tried with advantage.

Shampooing ought certainly to be employed in conjunction with galvanism especially in chronic cases if the extremity of the limb undergoes a degree of atrophy, or if contractions and fibrous ankyloses take place.

If the local arm bath is used, the author would recommend that the electrode out of the water be applied to the nape of the patient's neck, so that the whole nervous supply of the arm may be in the circuit. When the complete bath is employed there should be no breaking and making of the circuit. There seems to be no particular importance to be attached to the direction of the current.

201. **Sciatica and Lumbago.**—These two painful affections are particularly suited to treatment by the electric bath. Very good results are obtained by ordinary local galvanic treatment of both these conditions, but it is often more convenient and more agreeable to the patient

to be treated by means of the bath, and the results are very satisfactory. A course of twelve baths usually suffices to effect a cure. The ascending direction of the current should be preferred with the anode at the foot of the bath, or the anode covered with flannel may be placed near to the gluteal region on the affected side, the kathode remaining behind the shoulders as usual.

202. **General conclusions.**—As a *general tonic* the interrupted current bath is the best. It can be used most beneficially in many *hysterical conditions*; in *neurasthenia* and simple *debility*. The faradic bath is also of use in alleviating the distress connected with the discontinuance of the *morphia habit*.

The following conclusions have been arrived at by the various observers on the effects of the galvanic and faradic electric bath. *Metabolism* is promoted considerably. *Appetite and digestion* are improved. The *genital functions* are stimulated. *Circulation and nutrition* are benefited, *sleep* is notably restored, and new vigour is imparted to the mental and physical faculties. In short, the electric and especially the faradic bath is credited by all with a powerful *invigorating and refreshing* action upon the human frame.

There can be no doubt as to the efficacy of the faradic bath in states of debility and impaired nutrition, and especially in the various functional neuroses, *e.g.*, neurasthenia of any kind, and particularly sexual neurasthenia, nervous dyspepsia, palpitation, hysteria, hypochondria, *Basedow's* disease, &c. It is also of great value in promoting the recovery of patients after an attack of hemiplegia, the weakness, and also to a certain degree the rigidity of the affected parts, becomes notably improved in many instances.

Further, the galvanic bath is beneficial in tremulous states (mercurial and alcoholic tremor, &c.), and even in paralysis agitans, where it will affect at any rate a decided alleviation of symptoms. It is one of the most efficient forms of treatment in chronic rheumatism, in sciatica and in rheumatoid arthritis.

CHAPTER XI.

DISEASES OF THE NERVOUS SYSTEM.

Cerebral disease and hemiplegia. Epilepsy. Chorea. Tremors. Hysteria. Neurasthenia and hypochondriasis. Migraine and headache. Insomnia. Tinnitus aurium. Exophthalmos.

203. **Cerebral disease; Hemiplegia.**—In this and the following chapters we do not propose to enter into the whole subject of "Diseases of the Nervous System," but merely to bring forward quite briefly an account of the facts which have been established, and of the methods which are to be employed in the electrical treatment of these conditions.

To obtain successful results in cases of disease of the central nervous system it is not enough to apply treatment to the peripheral parts only; the seat of the lesion producing the paralysis or other symptom must also be brought under the influence of the current; this reasonable fact is often entirely lost sight of; sometimes by accident the central nervous system does secure a certain share of treatment, in cases where the indifferent electrode is placed on the nape of the neck for the sake of convenience, while the active electrode is being applied to the region of the affected muscles, but this by itself is not sufficient, for to produce the best results the treatment must be directed both to the seat of the lesion and to the seat of the symptoms. It is certain that changes are set up in the centres when their peripheral areas are stimulated, and in this way cures have been effected, even when the treatment has been applied only to the paralysed parts.

In *hemiplegia* good results are sometimes obtained by the faradic stimulation of the affected limbs, and this is a very valuable fact, because so little can be done in other ways to improve the condition of old hemiplegic patients. We have seen great benefit produced by the electrical treatment of such cases, and that not once or twice only, but frequently. The series of cases recorded by *Prof. Erb** seems to show that after an attack of hemiplegia the muscles may remain in a crippled condition from a sort of torpor of some part of the motor tracts, so that they remain for a time beyond the control of the will, although there may be no absolute interruption in the conducting paths. Thus a patient may at once recover much of his lost power after a single vigorous faradization of the affected limbs. It is therefore very important that this treatment by faradism should always be tried in cases where a patient is recovering imperfectly from hemiplegia. Treatment should not be commenced until about four weeks after the attack, in order to avoid all danger of setting up fresh mischief at the seat of the lesion, and it may be repeated three or four times in the course of a week. A certain number of patients will be very much improved thereby. The further treatment should be directed to the seat of the lesion in the brain, and galvanism is to be employed, the anode to the forehead and the sides of the head, and the kathode to the nape of the neck, the positive electrode being slowly moved to and fro (labile) without interruptions. This direction of the current has been chosen on account of its following the course of the motor tract. The current may be from one to five milliampères, and the active electrode should be of *medium* or *large* size, and should be adapted to the shape of the place on which it is applied. This treatment is to be carried out daily for four weeks, the duration of each sitting being not more than five minutes. If aphasia is associated with the hemiplegia the anode may be applied to the region of the third left frontal convolution and island of Reil. In cases of some months standing it might perhaps be useful to apply the kathode rather than the anode for the sake of its stimulating effect.

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* "Electro-therapeutics."

The objects aimed at in the systematic galvanism of the head in cerebral disease are as follows:—to promote the absorption of extravasated blood, to assist the circulation through the brain, to remove œdema and congestion, and to improve nutrition. All these may be classified as vascular effects, and a certain amount of evidence, partly experimental and partly clinical, has been collected, which seems to show that such vascular changes can be set up within the skull by long-continued and regular galvanic treatment. This is a promising field for investigation. *Lowenfeld* has claimed that anæmia of the brain may be set up by the kathode, and hyperæmia by the anode. It has been stated that a profound effect can be produced upon the cerebral circulation reflexly by faradizing the skin of remote parts; for instance, that faradization of the abdomen may set up so rapid a cerebral anæmia as to produce fainting (*Liebig* and *Rohé*). The present position of electricity in the treatment of cerebral disease is still but very imperfectly understood, nevertheless there have been a sufficient number of successful results to make the treatment very well worth a trial in every case, especially as the prospects of improvement from other modes of treatment are so slight. Even when the morbid condition itself is incurable something may be done to relieve troublesome symptoms, such as headache, sleeplessness, mental depression and so on.

204. **Epilepsy.**—This has been attacked by electrical methods, with a certain degree of success. *Arthuis* states that he has seen good results follow from statical electricity—he considers that the treatment to be effective should be continued for some length of time, but that it need not be pursued unless benefit is seen in the first two or three months.

Althaus says that in certain cases the continuous current may do a great deal of good. His method is "to direct the electrodes to the mastoid processes, the cervical sympathetic and those peripheral nerves in the domain of which an aura is repeatedly or occasionally experienced." He gives three cases where galvanism at once diminished the frequency of the attacks, and went so far towards effecting a cure that the intervals between the fits was prolonged from a few days to two months at least. The further history of the cases remains uncertain, as they were hospital patients and ceased to attend, but as it is probable that they would have returned if not cured, we may perhaps suppose that the benefit they received was permanent. The number of applications ranged from eleven to fifteen. *Erb* also reports that he has received a decidedly favourable impression from the treatment of epilepsy by galvanism. He advises that the anode be placed first on the side of the forehead, with the kathode to the nape of the neck, with a weak current for one minute, and secondly in the middle line of the head in front with the same current and for the same length of time, the kathode being over the occiput. The treatment of the neck and of the seat of the aura, as recommended by *Althaus*, should also be tried.

205. **Chorea.**—Statical electricity has been successfully tried in this disease. In 1849 *Dr. Golding Bird** reported that thirty cases out of thirty-seven had been cured by electrical treatment, while five of the others were relieved. The plan of treatment was the application of sparks to the spine. The shocks from a Leyden jar were found to be decidedly harmful. *Dr. Golding Bird* suggested that the benefit depended upon a cutaneous effect of counter irritation by the sparks.

The patient should be insulated and made to hold the metal rod or chain connected with one of the conductors of the electrical machine. An excitor consisting of a brass knob and insulated handle (fig. 29) is attached to the other conductor, and sparks taken from the spinal column and then from the affected limb, until a papular eruption is produced. In hemi-chorea the hand of the affected arm is made to hold the metallic rod or chain, if the movements are not too violent. In the case of children it is best to insulate the mother or nurse with the child in her arms, making either of the former hold the connected rod, the sparks can then be taken from the child's back and limbs.

In severe cases the treatment has to be repeated every day, or indeed twice a day; in less severe cases every other day or twice a week. Some patients are relieved after three or four applications of the treatment, but complete cure results after a varying time, according to the severity and duration of the attack and the frequency with which the treatment is repeated.

Writing on the same subject in the "Guy's Hospital Reports" in 1853, the late *Sir W. Gull* gives twenty-five cases of chorea treated by statical electricity. Nineteen were cured and five improved; only one resisted the treatment. He says: "The fact stands well established that electricity is at present to be ranked amongst the means at our disposal for the cure of chorea, and that in severe cases its effects are often truly surprising. Where other means cannot be employed; when the patient is scarcely able to swallow; where the skin is abraded from the prominent bones of the emaciated frame; when the powers of life seem nearly exhausted, sparks of electricity drawn from the whole length of the spine will often, after a few repetitions, effect a favourable change, and enable us to administer other means of cure."

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* "Lectures on Electricity and Galvanism," London, 1849.

(*Sir W. Gull* continued to hold these views to the end of his professional life, and when I was appointed to the charge of the electrical department at St. Bartholomew's Hospital, he advised me to turn my attention particularly to the treatment of chorea by statical electricity. The results I have had have been most satisfactory. *W.E.S.*)

Erb proposes the use of oblique galvanization of the head in chorea, but does not express any definite opinion as to its value.

Some cases of chorea treated recently by electricity are recorded by *Beard* and *Rockwell.* The methods used by them were "general faradization" or "central galvanization," the former method being used unless the patient seemed to bear it badly. Good results appear to have followed both plans of treatment; the point of most importance insisted upon by the authors being that the currents used must be gentle and agreeable to the little patients, and that all shocks or alarms are to be avoided.

It is difficult to estimate the true value of the results obtained from the electrical treatment of chorea, because the ordinary course of the disease is so uncertain, both in its duration and its severity, and because of the tendency to natural recovery.

It might be useful to employ electrical treatment in those cases which have lasted a long time, and resist the ordinary medical treatment by rest and drugs.

206. **Tremors.**—But little can be done with electricity in cases of tremor. In *paralysis agitans* it has been tried systematically (*Gowers*, *Berger*) without any success.

Althaus has seen relief follow the galvanic treatment of shaking palsy of long standing in several cases, but he does not clearly indicate his mode of treatment.

Beard and *Rockwell* give two cases of tremors in which relief was afforded by central galvanization.

The galvanic bath (§ 197) has been found useful in certain cases of tremor, especially in those due to toxic influences (alcohol, mercury, lead). Tranverse galvanization of the head has been recommended by *Chéron*, while *Erb* suggests the longitudinal or oblique galvanization of the head.

207. **Hysteria.**—Hysterical affections have been very largely treated by electricity, and from the peculiar nature of the affection, good results have followed the most diverse forms of electrical treatment. The moral effect of the treatment, particularly when it is associated with sparks or with shocks, is suitable to the state of mind of hysteria, and therefore the literature of Medical Electricity, from the time of *John Wesley's Desideratum* onwards, is full of more or less wonderful cures of such cases by electricity. At the same time the value of electrical treatment lies rather in the direction of relieving symptoms than of curing the morbid state, and it is necessary to be prepared for occasional difficulties

and disappointments, even in hysterical cases, although good results will usually be obtained. We must also be careful not to claim too much for the electrical part of the treatment when it is successful, for it may happen that the touch of an electrode will cure even when there is no current. Several cases of this kind have come to our notice. Strong galvanic shocks have been used for cutting short an hysterical fit, but the most useful rôle of electricity in hysteria is for the removal of paralyses, anæsthesiæ and spasms; for these symptoms faradism is most usually employed, either by means of an ordinary electrode or by the dry metallic brush. Statical treatment, especially the treatment by sparks, is quite as valuable in these cases, and has been very largely practised in Paris. Occasionally the continuous current is better, particularly where the complaint is of a painful point. These painful points can be successfully treated by the application of the anode, stabile, for five or ten minutes at a sitting, the commonest situations of the pain being over the vertebræ, or the sacrum, or the ovaries, or beneath the mamma. Hysterical aphonia can usually be dispelled by faradic currents applied to the throat from outside, and for the most part this method is better than the more severe application of the electrode to the fauces, or to the larynx, because the patient will not always submit to the latter method. For the hysterical condition, as distinguished from the special symptoms, it is advisable to make use of one of the methods of general treatment described in Chap. IX., namely, general faradization, central galvanization, or the electric bath.

The electrical treatment of hysteria does not consist merely in severe applications, the faradization may be briskly applied, but pain must not be deliberately produced; to punish his patient is not part of the medical man's duty, and unless the patient's confidence can be won by kindly firmness, the treatment will very probably be in vain.

Another very important consideration is the diagnosis between hysteria and organic disease of some obscure kind. It is not at all uncommon for hysteria to be associated with serious disease, for instance, with phthisis, moreover when the diagnosis has been based upon the alleged presence of a persistent localised pain in a female patient, it may after all turn out to be due to some serious latent mischief. We have known two cases where patients with early malignant disease of the vertebræ were supposed to be suffering from hysteria alone.[*]

208. **Hypochondriasis** and **Neurasthenia.**—In these conditions the general methods of electrical treatment are of great value; either the electric bath, general faradization or central galvanization may be used, with additional local treatment for any symptom which may be especially troublesome. The positive charge from a static machine is also very useful in certain cases. The value of the treatment may be due to a belief on the part of the patient that an extremely powerful agent (electricity) is being brought to bear upon his case—certain it is that the vague symptoms of these patients are sometimes dispelled in a wonderful way by electrical treatment.

The management of hypochondriacal patients requires a very great amount of care,[†] and in treating such cases it is important to attend to their psychical condition as well as to their bodily complaints. *Dr. Gowers* has insisted on the importance of the withdrawal of the attention of the patient from his physical condition, he says: "it is essential to make the patient realise how misleading bodily sensations often are regarding the actual condition of the parts from which the feelings seem to proceed, and how essential it is that the sensations should be disregarded, he should also be made to understand that his efforts to neglect them will not be at once successful and that perseverance for a long time will be necessary."

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[*] Cf. *Dr. Buzzard*, "Brain," 1890. "On the Simulation of Hysteria by Organic Disease of the Nervous System."

[†] A grave responsibility rests upon physicians who are consulted by these patients. The mere consultation, even when the advice is

It is probable that in neurasthenia a certain degree of functional disorder of some part of the nervous system is present; the condition has been divided into two chief varieties, *neurasthenia cerebralis*, where the symptoms are sleeplessness, low spirits, sensations in the head, (giddiness, weight, feeling of lightness, &c.) and *neurasthenia spiralis*, in which muscular weakness, languor, pains in the back, and numbness of extremities are more especially complained of.

Besides these symptoms the patients usually suffer from dyspepsia, with constipation or less often with diarrhœa, accompanied by a feeling of prostration, and very much may be done for their general neurasthenic condition by a careful regulation of the bowels.

When the sexual organs are complained of, galvanism can be applied in the manner recommended by

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wise, helps to perpetuate the morbid state, and when all that can be done to remove actual disorder has been accomplished it is often right to refuse to be any longer a passive party to the perpetuation of the symptoms. Sometimes such a refusal, if the grounds for it are made clear, will do more real good to the sufferer than can be achieved by any other means.' *Gowers.*

Erb, namely, the anode of large size to the lumbar spine, the kathode to the groins, the penis or scrotum, and the perineum, using strong currents for one or two minutes at a time. Faradic treatment applied to the same parts is also said to be of great use in some cases. It has further been proposed that one pole should be introduced into the urethra, or the rectum, the other pole being applied to the lumbar spine.

209. **Migraine and headache.**—Although it might have been expected that electrical treatment would benefit this disorder, yet but little success has hitherto been obtained, at least from galvanic or faradic treatment. *Erb* has once succeeded in arresting an attack by galvanism. We have also seen a one-sided headache instantly dispelled by the application of the anode to the forehead, and *Dr. Poore* has more than once removed a troublesome headache by a single application for a few moments of a weak current to the head. Statical treatment has been rather more successful. *Arthuis* and *M'Clure* both speak of having obtained favourable results, the latter gives an account of a severe case, in a lady who had had attacks almost weekly for fourteen years. The treatment was by the souffle to the head. After eight or ten applications the intervals became longer, and the patient was able to do much more without bringing on an attack. The patient though much relieved was not cured completely. It is not clear from the account whether the treatment was applied during the period of headache or during the intervals, but probably it was the latter. *Dr. M'Clure* recommends the use of negative electricity in form of the souffle or electric breeze.

Arthuis says that the results he has obtained in migraine justify him in saying that although statical treatment does not cure the disease, yet it is the best mode of treating it, he considers that the cases most easily influenced are those occurring in women at or near their menstrual periods, and those which depend upon digestive troubles. His procedure is to use the souffle, frictions,* and sparks applied to the whole body, especially to the forehead and the epigastrium; the duration of each sitting being from eight to ten minutes, and the course of treatment being extended over a period of several months.

Other forms of headache have also been treated by galvanism, but without definite results. *Althaus*, however, is of opinion that they can usually be relieved by a gentle faradism with the electric hand, or by a gentle continuous current, and he has seen a large number of cases in which one or other of these methods has proved successful.

210. **Insomnia.**—Electricity is very useful in many forms of sleeplessness. According to *Prof. Erb* a decided inclination to sleep is often induced by the electrical treatment of the most widely differing parts of the body, but especially of the head and neck. General faradism or the faradic bath are the best methods of treatment, but even local faradism or local galvanism of a limb is frequently followed by a well marked soporific tendency.

211. **Tinnitus aurium.**—Subjective noises in the

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* *Electrical frictions* are carried out by moving the knob of an excitor (fig. 29) lightly over the surface of the body, through a layer of dry flannel. The flannel may be worn as a well-fitting garment, or it may be tied round the knob of the excitor. This latter plan is best for the face and hands. In either case the effect is to produce an abundant discharge of very short sparks, whose length depends upon the thickness of the flannel. The sensation is one of warmth and pricking.

ears are frequently benefited by galvanism. From what has been already said in § 173, it appears that when the tinnitus is associated with an irritable state of the auditory nerve, good results may be expected from the sedative action of the anode, which may be applied by a small electrode to the ear, or to the mastoid process just behind the ear, or to the skin immediately in front of the tragus. We have treated a very large number of patients for this complaint, and have adopted an uniform plan of treatment, the active electrode (anode) is bifurcated (fig. 75) and has a spring to retain it in its position in front of the tragus. It is thus applied to both ears at once. The parts in contact with the skin should not be of less diameter than two centimetres. If the surface of the electrode is too small some soreness of the skin may be produced at the points of contact. A small pad of moist absorbent wool makes the best covering. The indifferent electrode is placed at the back of the neck, where it is kept in position by the pressure of the clothing; and a good galvanometer and a rheostat should be included in the circuit. A simple and convenient form of graphite rheostat is made by *Mr. Schall*, which enables the operator to introduce a resistance of 10,000 ohms into the circuit quite gradually. When everything is ready the current is slowly and steadily raised by the current collector to five milliampères, (the rheostat being at zero) and allowed to pass for ten minutes. As the resistance of the skin diminishes the current will increase slowly, the galvanometer may be allowed to indicate eight milliampères, each ear is then receiving four. If the current should be inclined to rise higher the rheostat must be brought into use to keep it at that strength. The patient should be instructed to pay attention to the noises and to give notice of any change occurring in them in the course of the sitting. In favourable cases the noises will diminish during the passage of the current; if the current be too quickly reduced at the end of the treatment the noises may return as loudly as before, but if it be reduced very slowly and gradually this should not happen. On this account the rheostat is an important part of the apparatus; at the end of the sitting the current is to be reduced by the rheostat first and afterwards by the collector. It generally happens that the tinnitus is gradually dispelled by the treatment, at first the relief is quite temporary and the noises will probably return within a few hours, but after each sitting the period of quiet is longer until finally they disappear altogether. If the sittings are repeated daily for the first week much time will be gained, afterwards it will be sufficient to apply the treatment twice a week for a fortnight or three weeks, or a month, according to the progress of the case.

Tinnitus complicates nearly all the different forms of ear disease, for instance, it may depend upon the accumulation of wax, or it may be due to some other temporary disorder of the ear, which can easily be cured by proper treatment, or it may occur in patients whose auditory apparatus is normal, as a part of some general morbid condition.

More commonly, however, some chronic mischief exists and the removal of the subjective noises may be a matter of great interest to the patient, even apart from his deafness or other ear troubles. Very many of these cases obtain great relief from galvanism.

The causes of tinnitus can be grouped into four divisions:—1. Morbid constitutional states, including debility, renal disease and the effect of drugs, such as quinine and salicylate of soda. 2. Disorders of the peripheral auditory apparatus. 3. Disorders of the central (cortical) auditory apparatus. 4. Reflex disturbances, especially from the region of the fifth cranial nerve.[*] Of these four divisions the largest and most important is the second; and a majority of the patients suffering from tinnitus belong to this group. Galvanic treatment is able to do a very great deal for these cases provided it be properly managed. If it is not done carefully the results will be unsatisfactory.

It has been objected to the galvanic treatment that it is difficult, and that the results are uncertain, and at best only temporary, but when so little can be done in other ways for these patients it is at least a gain to be able to relieve by galvanism the very distressing symptom of tinnitus. Out of a very large number of patients who have been under our treatment for noises in the ears, the majority have been completely freed by a course of galvanism applied in the way already described. Some of them certainly have returned after the lapse of several months for further treatment, and in them the symptom has for the most part again yielded promptly to the renewal of galvanism.

212. **Exophthalmic goitre.**—This disease has been frequently treated by electricity, and in a fair number of cases the treatment has been followed by good results. It has been assumed that the seat of the disease is in the vasomotor system, and especially in the cervical sympathetic. It is important to bear in mind, as has been pointed out by *Gowers*, that the sympathetic system is represented in the brain, and on this account the

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[*] See *Dr. Macnaughton Jones* "On Subjective Noises in the Head and Ears," p. 116, "Dental Reflexes," London, *Baillière Tindall and Cox*, 1891.

treatment should not be confined too strictly to the region of the neck.

Erb calls attention to the frequent association of neurasthenic symptoms with exophthalmos, and this also suggests a cerebral origin for this peculiar morbid condition. *Dr. Cardew* has devoted considerable attention to the electrical treatment of exophthalmic goitre, and he has reported* a short series of cases where galvanism produced great improvement in the symptoms. In nearly all of them the frequency of the pulse-rate was reduced as much as twenty to thirty beats per minute, the enlargement of the thyroid was greatly diminished, and the nervous condition of the patient was very much improved. He suggests that the galvanic treatment should be carried out by the patients themselves three times a day, and also at other times if the palpitation of the heart should become severe. He advises that a current of two to three milliampères should be applied for six minutes; the anode to the region of the lower cervical spine, the kathode to the side of the neck, labile from the mastoid process to the clavicle. The two sides of the neck should be treated alternately, and the patient should persevere with the treatment for two months at least. *Dr. Cardew* has also proved that the diminished resistance of the body which had been observed in this disease is due simply to the increased perspiration and moisture of the skin.

We have in one case seen remarkable improvement follow the faradic bath after patient treatment by galvanism applied locally had failed to do any good.

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* "Lancet," July, 1891.

CHAPTER XII.

THE NERVOUS SYSTEM (*Continued*).

The spinal cord. Treatment of paralysis. Myelitis. Locomotor ataxy. Infantile paralysis. Progressive muscular atrophy. Diphtheritic paralysis. Paralysis after specific fevers. Lead palsy.

213. **The spinal cord.**—The spinal cord can be easily reached by the galvanic current, less easily by the faradic. The use of galvanism in disease of the spinal cord is indicated for the sake of its stimulating, vasomotor, alterative and catalytic effects (§ 175), and treatment has been followed by very good results in many cases of simple functional disturbances, and also to a less degree in chronic degenerations.

The current should usually be applied longitudinally, with large electrodes (stabile) five to twenty milliampères for two or three minutes, the time may be prolonged after the patient has become accustomed to the treatment. *Erb* advises the descending direction for irritative states, the ascending for states of weakness or chronic degeneration. When the disease is limited to a small portion of the cord, a transverse direction of the current may be tried, one pole being placed on the vertebral column over the affected part, and the other pole on the front of the body at the same level.

214. **Treatment of paralysis.**—Certain fundamental principles of treatment apply to nearly all cases of paralysis. There must be (1) treatment of the seat

of disease, brain, cord, or nerves, as the case may be, and (2) treatment of the paralysed muscles. The seat of disease is to be attacked in the hope of setting up trophic or vasomotor changes there, in order to remove the cause of the paralysis, and the muscles are to be treated in order to maintain their nutrition and their activity; moreover, stimulation of the peripheral parts may also act usefully by influencing the central organs through the medium of sensory nerves, and in a reflex manner may set up motor impulses along the nerves to the paralysed parts, this tends to restore the conductivity of the nerve if that be at fault, in other words, such peripheral treatment has as its object the restoration of the normal influence of the will on the muscles. When the affection is purely motor, and the sensory functions of the paralysed parts are normal, this reflex mode of influencing their motor centres is simple, and it follows then that peripheral excitation of a limb in infantile paralysis, or of the face in *Bell's* palsy, is clearly indicated. The good effects obtained by *Duchenne* from faradism of the muscles in infantile paralysis, may have been brought about in this manner. In proof of the reflex effects which can be produced when a nerve trunk has been injured and repair is taking place, it is often noticed that voluntary power returns a little before the return of galvanic and faradic irritability in the nerve (§ 167). Here direct treatment of the nerve trunk, by applying the electrodes to it above the seat of injury, or indirectly through the agency of reflex stimulation of its centre, will prove useful, and will accelerate recovery. *Erb* says: "A hindrance in the motor conduction, which cannot be overcome by the will, may perhaps be conquered by a stronger artificial stimulation and the way thus made clear for voluntary excitation.

Hence if we allow the electric irritation to act energetically above the seat of lesion, the hindrance may perhaps be in this way removed."

The paralysed muscles are to be treated by applications of the kathode, which must be well moistened and moved slowly and firmly over the affected muscles; the current may be between five and ten milliampères, and the duration of treatment ten minutes. For children five milliampères is quite sufficient. It is important not to use electrodes which are too small. The medium size (five centimetres) is suitable, and less painful than smaller sizes, because the density of the current at its surface is less. If five milliampères should seem to be painful to the child the current must be reduced to four or three. In addition to the stabile applications the current may be opened and closed or even reversed suddenly from time to time, for the sake of exciting contractions in the paralysed muscles. The indifferent electrode is to be placed over the spine in the neigbourhood of the central lesion.

When faradism is used a similar method of application may be adopted, the current must be carefully regulated, and the duration of treatment must be shorter (five minutes). Or both poles may be applied to the affected part, one being buckled round the limb in a position close to the nerve trunk, while the other is manipulated over the muscles, or lastly, both electrodes can be applied direct to the muscle. If the muscles do not respond to faradism it is better to use galvanism, although even in such cases faradism is not altogether without effect. *Duchenne* has insisted on the fact that a few functional and living fibres may be present in a muscle which apparently has entirely wasted, and he maintains that round these, as centres, fresh muscle fibres can be encouraged to develop by patient faradic treatment. It is not always easy to be quite certain whether such surviving fibres are present or not, but he says that after long practice he had learnt to recognise their presence, even when their contractions were too weak to produce any movement in the bony levers to which they were attached.

215. **Myelitis.**—In acute myelitis electrical treatment should be avoided as it is likely to do harm. In chronic myelitis it may be employed with advantage in the manner already indicated in § 213. When there is much rigidity, and the reflexes are excessive, the galvanic bath may afford some relief to the symptoms.*

216. **Locomotor ataxy.**—Electrical treatment has not proved effectual in arresting this disease. But yet for the relief of some of the symptoms, and especially for the *pains*, electrical treatment should be tried, for it has often afforded much benefit. A few cases have been reported in which substantial improvement has followed electricity applied in the earlier stages of the disease.

217. **Infantile paralysis.**—There is no doubt that electrical treatment is of the utmost value in this disease. Unfortunately the duration of the treatment in severe cases is very long, and it requires great perseverance on the part of the physician and on that of the parents to keep it up. On this account it often happens that the patients treated in hospitals show more improvement than in private practice. In the latter case the treatment is naturally a costly affair, while at the hospital this is not so, and the mothers bring their children regularly for months. Indeed, in many cases,

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* *Steavenson* is certain that the electric bath is of great value for the tremors and rigidity of chronic myelitis.

they are able to recognise the improvement in their children's muscular powers more readily than the medical officers, and they are both willing and anxious to continue attendance for long periods, even in the less promising cases.*

The course of the disease is as follows :—the child is brought with a history of a past febrile attack, after which it was noticed that a limb or limbs had become paralysed. Power not returning to the paralysed parts the little patient comes sooner or later for medical advice, with wasting, paralysis and the reaction of degeneration in some or all of the affected muscles. *Duchenne* pointed out that of the muscles affected at the onset of the disease some may be more seriously injured than others, and waste more rapidly. The electrical reactions also vary, those muscles which waste rapidly soon develop the reaction of degeneration, others, though paralysed, may retain their power of contracting to faradism, wholly or partly for a long time; the latter will improve even if not treated, but their recovery will be greatly promoted by treatment. The others may not improve at all, remaining wasted, and showing the reaction of degeneration for years, or until their muscular fibres have all atrophied, when they will naturally exhibit no electrical reactions at all.

Duchenne looking at the disease from the point of view of faradism only, regarded even these latter muscles as being at least in part within reach of treatment, and he insists that a very minute and careful examination may reveal a few contractile fibres still remaining, even after four or five or six years of paralysis and atrophy. If such living fibres can be found then they may be encouraged by faradism to develop, and to act as centres for the growth of new muscular fibres until considerable improvement in size and power may be obtained; on the other hand if no such living fibres exist the prospects of improvement by faradization or any other treatment are very slender indeed. With the aid of the galvanic current, however, perseverance will succeed in greatly improving muscles which are extremely wasted, and show complete RD with greatly diminished galvanic excitability. Complete recovery must not be expected in such muscles, all that can be accomplished by the treatment is to make the most of such fibres as are still attached to a living ganglion cell, and by stimulation to invite a further development of new fibres round those which have escaped. For the method of treatment see § 214.

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* Those private patients who have persevered have nearly all of them improved.—*W. E. S.*

The RD may be fully developed by the seventh day, galvanic irritability may disappear in six months, or it may persist for four or five years. Any muscles or groups of muscles may be affected by the disease, perhaps the most common seat is in the tibialis anticus and the peronei of the leg and the deltoid in the arm.

The deformities which result from the over action of muscles, when their antagonists are damaged by this disease, are well known. Many of the various forms of club-foot are produced in this way, and originate from infantile paralysis. It may be worth while to give briefly the mechanism as summed up by *Duchenne*:—There are six muscles (three pairs) with the special function of moving the foot upon the leg. (1) The calf muscles and the peroneus longus. (2) The tibialis anticus and the extensor communis digitorum. (3) The tibialis posticus and the peroneus brevis. The first pair extend the foot, the second pair flex the foot, and the last pair produce lateral movements.

The movements of flexion and extension by the first groups include lateral movements also, because the pull of the muscles is not quite direct. When simple flexion or simple extension movements are required, they are produced by the combined action of both components of each pair ; thus, the calf muscles extend and adduct, while the *peronei* extend and abduct, the *tibialis anticus* flexes and adducts, the *extensor communis digitorum* flexes and abducts. Of the remaining pair, the one, the *tibialis posticus*, adducts, and the other, the *peroneus brevis*, abducts. There are many other composite movements carried out by these muscles, but individually considered their actions are those just mentioned. The special deformities likely to follow the paralysis of any of these muscles, or of any combinations of them, can be predicted, if their special action, and that of their antagonists, are borne in mind. Some of these muscles play an important part in preserving the arch of the foot, and when they are paralysed a tendency to flat foot is well marked. An opposite condition of exaggerated arch of the foot is also common, it was first described carefully by *Duchenne*, under the name of *griffe pied creux*, or hollow claw foot. It is of importance in that it shows the effect of paralysis of the *interossei*.

These muscles flex the proximal phalanx and extend the distal phalanges of the toes by a single movement, they also produce lateral movements of the toes. Their action supplements those of the other flexors and extensors of the toes. The long flexors, that is to say, the *flexor longus pollicis*, *flexor longus* and *flexor brevis digitorum*, flex only the distal phalanges, while the extensors, *extensor longus and brevis digitorum, and extensor proprius polli-*

cis, extend only the proximal phalanx. In the absence of the antagonising action of the *interossei* the long extensors extend the first phalanges permanently, and the long flexors flex the second and third phalanges also permanently, and this produces a claw-like attitude of the toes. The abductor and flexor brevis of the great and of the little toes act as the interossei, and when they are paralysed the claw shape becomes more intensified.*

218. **Progressive muscular atrophy.**—The clinical group of muscular atrophies has been divided in recent years into two parts. 1. Those owing their origin to lesions of the anterior cornua. 2. Those dependent on primary disease of the muscles themselves. Muscular atrophy is also produced by neuritis and by injury to the trunks of nerves.

In the disease known as *progressive muscular atrophy*, electrical treatment may be employed, but the prospects of cure are not very good. Still in default of any other better method of treatment it is reasonable to believe with *Dr. Gowers* that the influence of electricity is in the right direction, and seeing that patients are often very anxious to make a trial of it, it is quite right that efforts should be made to obtain alleviation of the symptoms by means of galvanism. *Erb* has seen relief, retardation, and even arrest of symptoms, especially in early cases, and advises treatment of the spinal cord, particularly the cervical enlargement, which is so frequently the seat of the most severe atrophic changes. His method is to commence with the anode to the cervical spine, and the kathode to the cervical sympathetic, followed by the kathode to the spine, and the anode to the sternum, the lumbar enlargement, or the peripheral nerves. He insists especially upon the importance of the action of both poles being brought to bear successively upon the affected regions of the cord. Finally, the affected muscles are to be galvanized (kathode, labile) or faradized, the indifferent electrode being at the nape of the neck. The current should be "moderately strong," but too vigorous a treatment is not advisable.

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* For a short abstract of *Duchenne*'s remarks on the hollow club foot, see *Erichsen*'s "Science and Art of Surgery," vol. ii.

Erb also says that although electrical treatment may arrest or retard the progress of the disease, that yet it is in no way a cure, and that the curative results said to have been obtained are generally the consequence of errors of diagnosis, especially in cases of neuritis, infantile paralysis, and atrophy after joint affections. He also considers that the idiopathic muscular atrophies have a more favourable prognosis, and he has seen great benefit follow electrical treatment in long standing cases of that kind. However, *Duchenne* declares that by means of faradism he has been able to arrest the progress of the disease in an advanced case,* to re-establish the power of the diaphragm, which had become seriously involved, to restore the bulk and vigour of an important muscle (the biceps), to dispel the fibrillar twitchings, and that the recovery was persistent for several years, in spite of the fact that the patient returned to hard manual labour, a condition of things extremely likely in *Duchenne's* opinion to bring on a relapse. He is certain that he has seen increase in the bulk of a muscle from faradization, indeed he says that it follows fairly often, but only in cases where the muscle had not altogether lost its faradic irritability. He lays down precise instructions for the method to be adopted as follows :—

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* The case is described and figured, and seems to have been undoubtedly one of progressive muscular atrophy, "Elect. Localisée," 3rd Edit., p. 500.

1. To pass the moistened electrodes over the surface of each of the affected muscles, keeping them close together, and using a current of low intensity (primary current).

2. To stimulate the muscles moderately, and with a current which is not interrupted very frequently.

3. To treat only the muscles which react to faradism, and to pay most attention to the most important muscles, and to terminate the sitting by a mild faradization of any muscles which may be threatened with an invasion of the disease.*

We have presented the views of both these authorities (*Erb* and *Duchenne*) because it might be useful to compare together a series of cases treated in each of the two ways. It may be that both writers are to a certain extent prejudiced, each in favour of his own method, but *Duchenne* at any rate is willing to allow that galvanism may be of use as an aid to the treatment by faradism. *Erb* on the other hand dismisses faradism by saying that it would only be employed in the absence of a continuous current battery. *Gowers* is of opinion that if regular electrical treatment be applied on one side only to a patient with progressive muscular atrophy in both arms, no difference will be detected in the rate of wasting of the two sides.

The electrical reactions in progressive muscular atrophy are a little complicated, because the gradual destruction of the muscle, fibre by fibre, produces a condition in which some fibres react normally to faradism and galvanism, while others respond only to galvanism, with ACC>KCC; it may sometimes be possible to recognise in a muscle that a sluggish contraction appears after the quick contraction, the latter being produced by the sound fibres and the former by those which have the reaction of degeneration.

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* For the muscles most usually attacked, see *Duchenne*, *op. cit.*, p. 494, or *Gowers*' "Diseases of the Nervous System," p. 359.

219. **Paralysis after diphtheria.**—The paralysis which follows diphtheria tends for the most part to spontaneous recovery, unless the medulla oblongata and its nerves are so seriously affected as to cause death by direct interference with the respiratory and cardiac mechanisms. The electrical reactions vary. There may be the reaction of degeneration, or simply a quantitative diminution, or they may be normal. Electrical treatment may be employed to hasten recovery, and it is to be carried out generally according to the plan laid down in § 214 for the treatment of paralysis, and will of course depend upon the particular seat of paralysis in each case. The question whether diphtheric paralysis is to be regarded as due to coarse changes in the cord, or in the nerves, or whether it is not rather a toxic paralysis, has so far not been clearly settled. The paralysis which occurs after other specific fevers, such as typhoid, small-pox, scarlatina, and others, is perhaps of a similar nature. In some of these, however, and also sometimes after diphtheria, permanent changes are produced, with symptoms of chronic myelitis or chronic neuritis.

220. **Lead palsy.**—In paralysis due to lead the reaction of degeneration is usually present, in fact it is an early symptom, and as has been shown (§ 171) it may precede the paralysis. The partial reaction of degeneration may be present in some of the affected muscles, and some may even show simple diminution.

Erb says that "from the long duration of lead paralysis and the frequently occurring relapses, the condition of the electrical excitability may be considerably complicated, indistinct, and confused, so that sometimes nothing definite can be evolved from the electrical examination." Treatment by electricity is of the greatest value, muscles which have lost their galvanic irritability almost completely may be seen to recover it under this treatment, even after a few applications.

As regards treatment, *Erb* advises careful galvanization of the spinal cord, and, as the muscles of the upper limb are those most commonly affected, he carries this out by the application of the anode (large size) to the region of the cervical enlargement, and the other to the sternum, using a current of ten to twenty-five milliampères, stabile, for two minutes, the direction is then reversed (but not abruptly) for the same period, and the paralysed muscles are then galvanized with the kathode, labile, and fairly strong currents for two or three minutes, the anode remaining on the nape of the neck. If the muscles respond badly, a few reversals of current may be used at the termination of the treatment.

Erb defends the direct treatment of the spinal cord on the ground that even if the lesion in lead poisoning be one of the nerve trunks, and not of the spinal cord, there are nevertheless trophic centres in the cord itself which require stimulation.

Treatment must be long continued to obtain good results. The value of faradism in this disease must not be forgotten. Although more recent writers advise galvanism almost exclusively, the experiences of *Duchenne* prove that something can be done by faradism also. He writes that in lead palsy recovery will follow the treatment, "almost always," even if the faradic irritability has completely disappeared from the muscles. Reference to § 217 will show that this opinion is even a more confident one than he was able to give for muscles which had lost faradic irritability completely after infantile paralysis.

Duchenne's method is to use the primary current, with rapid interruptions, and a powerful stimulation, for ten minutes; the treatment should not be prolonged beyond that time lest fatigue and pain be produced.

He has commonly found distinct improvement after ten or twenty sittings, even if the affection is of long-standing. The deltoid recovers quickly, the radial extensors quicker than the ulnar. *Duchenne* advises to determine which of the extensors of the wrist are affected, in order to apportion the treatment to each of them in a proper manner. He does this by telling the patient to raise the forearms and pronate them. If the muscles are all three of them paralysed there is then no power of extending the wrist at all. If the extensor carpi radialis brevior can act, extension of the wrist is possible when the fingers are first flexed. If the extensor carpi radialis longior can act, then slight extension is associated with abduction, and if the extensor carpi ulnaris can act, there will be adduction.

It is extremely important when the lead poisoning is a result of the patient's occupation that he should be advised to give it up altogether, otherwise relapses are almost certain to follow his return to work. When the the patient returns to his occupation partly cured, before the end of his long treatment, he is almost certain to relapse.

CHAPTER XIII.

THE NERVOUS SYSTEM *(Continued)*.

Injuries of nerves. Pressure palsy. Neuritis. Facial palsy. Paralysis of ocular muscles. Neuralgia. Sciatica. Spasm. Wry neck. Writer's cramp. Tetany. Anæsthesia. Anosmia. Optic atrophy. Nervous deafness. Muscular atrophies.

221. **Injuries of nerves.**—From what has been said in §§ 166 to 169 it follows that injuries of nerves are likely to be followed by the reaction of degeneration in the muscles which they supply, and this does always follow if the injury to the nerve has been sufficiently severe. But, as such injuries may be of any degree of severity, it will be found that the reaction of degeneration is not invariably produced, for in the slighter cases the nerve recovers before degenerative changes have had time to follow, or indeed the injury may be of such a kind as to impair both motor and sensory conduction for a time without interfering with what may be called the trophic conductivity of the nerve trunk or setting up an actual neuritis.

In the examination of cases in which an injury to a nerve is suspected the anatomical arrangement of the nerve supply must be carefully kept in mind.

The phenomena produced in marked cases of injury to nerves are loss of motor power, impairment or loss or perversion of sensation, and diminished temperature in the area of distribution of the nerve, with trophic changes in the muscles (RD) and in the skin. The "glossy"* skin of nerve trunk disease is well known, and easily recognised.† Certain nerves are especially subject to injury, those of the upper extremity being affected in a very large proportion of the cases. The commonest causes are:—1. Division or laceration of nerve trunks in accidental wounds, particularly wounds about the wrist from broken glass. 2. Severe inflammation round the wrist or elbow joints. 3. Contusions, especially of the shoulder or the elbow, or dislocations of the same parts. 4. In fractures of the upper limb, too, the nerve may be involved in the callus thrown out during the process of repair.

Electrical treatment is of the greatest value in all cases of injury to the nerves. In many of the less severe cases electrical treatment is sufficient by itself for the restoration of the normal condition. When the nerve has been completely divided, the electrical treatment becomes an important adjunct to the surgical procedures which are necessary for the union of the divided nerve.

When the ulnar nerve has been completely divided near the wrist the symptoms produced are:—1. Paralysis with wasting and the reaction of degeneration in the hypothenar eminence, in all the interossei, in the two ulnar lumbricales, and in the adductor and flexor brevis (inner head) of the thumb. After a time the deformity known as the "clawed hand" is produced. The palm becomes thin and flat, the heads of the metacarpal bones become unduly prominent, the proximal phalanges are over-extended, the distal phalanges are permanently flexed. This is the result of the paralysis of the interossei. It has already been shown (§ 217) that in the foot the action of the long flexors of the toes is to flex the distal phalanges only, and that of the long extensors is to extend the proximal phalanges, and that when the interossei are paralysed the clawed attitude of the toes is produced in consequence. The mechanism is the same in the case of the hand, the interossei flex the proximal phalanges and extend the distal ones; and so supplement the movements of the fingers which are performed by the long flexors and extensors. 2. Loss of sensation in the little finger, and the ulnar half of the ring finger both front and back, and in the corresponding part of the palm and the dorsum of the hand.* 3. Trophic changes are produced in the skin and finger nails of the anæsthetic area, often with œdema; the temperature of the part is lowered, and sometimes there is very severe pain of a burning character, to which the name of "causalgia" has been given, this is not very common, nor is it usually present when the nerve has been completely divided. When it exists the temperature is raised above that of the opposite side, and the patient experiences a sensation of heat, and seeks for relief by cold applications.

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* The fingers become tapering, smooth, hairless, almost void of wrinkles, glossy, pink or ruddy, or blotched as if with permanent chilblains. *Paget*, "Med. Times and Gazette," 1864.

† For a valuable work on the subject of Injuries to Nerves and good coloured illustrations of glossy skin, &c., see *Bowlby* "Injuries and Diseases of Nerves."

After division of the median nerve at the wrist the conditions are different, the clawed hand which is so characteristic of the divided ulnar nerve is not present, and the chief feature is the wasting of the thenar eminence, the *abductor*, *opponens* and outer head of the *flexor brevis* of the thumb are paralysed, atrophied, and show the reaction of degeneration. There is loss of sensation in the thumb, index, middle, and half the ring fingers, and in the corresponding part of the palm, and of the two distal phalanges of the same fingers on the dorsum of the hand.

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* *Bowlby* "loc. cit."

For the symptoms following the division of other nerves *Mr. Bowlby's* book should be consulted.

222. **Pressure paralysis.**—The musculo-spiral nerve is often injured from the pressure of a crutch, or from the weight of the body resting upon the arm during heavy sleep. In crutch palsy the pressure upon the nerve is higher up the arm, and the triceps is usually paralysed. In sleep palsy the triceps may escape. As the musculo-spiral nerve supplies the extensors of the forearm, hand and fingers, and the supinator longus and brevis, wrist-drop is produced in this form of paralysis; the affection of the supinator longus helps to distinguish it from lead palsy. The affection of sensation may be slight or severe.

Paralysis from pressure has been thought to be secondary to compression of the blood-vessels of the limb producing anæmia of the nerve, but a case which came under our observation some years ago of a pressure palsy in the leg points rather against this view. In that case the pressure was on the great sciatic nerve at the back of the thigh, and there could not have been any compression of the femoral artery. The patient was a young man who attended a meeting, and in order to have a better view of the proceedings he sat upon the back rail of his chair; at the close of the meeting he was unable to use his leg and was assisted home. The treatment consisted in faradism of the limb, and recovery followed in a week or two. There was paralysis of the calf muscles, of the tibialis anticus, and of the peronei, the extensors of the leg were not affected. Sensation was unaffected.

Pressure palsies may be treated by faradism or by galvanism. In the milder cases, when the electrical reactions are not impaired, faradism is generally enough to bring about a favourable result; in the more severe cases, where the reaction to faradism is weakened or abolished, galvanism is to be used, in the manner already laid down for the treatment of paralysis (§ 214).

When the reaction of degeneration is present the duration of the paralysis will be longer than in the milder cases, and the prognosis must also be a guarded one, until the actual condition of the nerve at the seat of injury can be made out.

In those cases where there has been complete division of a nerve, recovery cannot be expected until after the divided ends of the nerve have been united. When that has taken place, electrical treatment will greatly assist the restoration of the paralysed and wasted parts, even though a year or more has elapsed since the injury, and in cases where the atrophy and degeneration of the muscles has been extreme.

Some of the cases of severe contusion of the nerve trunks are not relieved by electrical treatment. If the nerve has been permanently damaged by the injury it has received, then degeneration and atrophy will set in and will progress in spite of the most assiduous electrical or other treatment; fortunately it is not usual for the nerve to be so completely destroyed, and in most cases, even of severe injury to the nerves, persevering treatment will do very much to promote recovery.

Duchenne says that "assuredly it is in cases of traumatic paralysis of the nerves that faradization yields the most fortunate results." He has remarked that the return of painful sensations in a previously anæsthetic part is a favourable symptom, and has observed that electrical reactions (to faradism) may not return until after the power of voluntary movement has been re-established.

He is satisfied that it is unwise to trust too much to the chance of spontaneous recovery after injury of nerves, and has seen electrical treatment afford immediate benefit in a case for which the expectant treatment had done nothing during a twelvemonth. He advises faradism applied to each paralysed muscle in proportion to its degree of paralysis, and is of opinion that the continuous current with interruptions is a valuable auxiliary to faradic treatment.

Where possible the anode should be applied to the nerve trunk above the seat of injury, and the kathode labile to the paralysed muscles, with interruptions or reversals.

223. **Paralysis of the deltoid muscle.**—The circumflex nerve is sometimes injured by blows on the shoulder, by dislocation of the shoulder joint, or in other ways, thus it may be present in crutch paralysis. The symptoms are inability to move the arm outwards (abduction).

Sometimes it happens that the anterior parts of the deltoid muscle may be affected while the posterior part escape, or *vice versâ;* the nerve supply of the muscle is by two distinct branches of the circumflex nerve, one passing beneath the humerus to the posterior half of the muscle, and the other turning upwards to the anterior part. Either of these branches may bear the brunt of an injury.

The skin over the deltoid also receives filaments from the circumflex nerve, and loss of sensation there may be associated with the muscular paralysis. In a patient under our care lately there was partial reaction of degeneration and wasting in the posterior part of the deltoid, while the anterior part was normal; the cause of the injury was an abscess at the back of the shoulder for the evacuation of which a long incision had been made; there was a patch of anæsthesia over the paralysed area. The muscle recovered perfectly under galvanism.

224. **Neuritis.**—Nerves which have been injured may become the seat of a chronic neuritis, and this may spread along the nerve and prove very troublesome, and it may even lead to permanent damage to the nerve trunk.

When the parts around a nerve are inflamed the nerve trunk may share in the morbid process, or neuritis may be produced by the gradual compression of a nerve in a mass of fibrous tissue. In these cases a dissection, to free it from the scar tissue which is compressing it, is indicated. Neuritis also develops in the course of certain diseases, for instance after some specific fevers, and part of the symptoms of locomotor ataxy are probably due to a neuritis of the peripheral nerves. The condition known as alcoholic neuritis has attracted a good deal of attention of late years. Neuritis may also be produced by cold and exposure. The chief diagnostic feature of the forms of neuritis is the occurrence of pain associated with the paralysis, wasting, and impaired sensation, the pain is an important aid to diagnosis. Often there is thickening and tenderness of the affected nerve trunks which can be felt, and the muscles are also tender in many cases (*Gowers*).

In the acute stages of neuritis electrical treatment is not to be recommended, in those which are not acute the anode is to be used stabile or labile over the affected parts, the kathode being placed either on a sound part of the same nerve higher up or else on the nape of the neck; a current of five to ten milliampères should be used for ten minutes at a sitting.

In cases of long standing where the morbid process is one of chronic interstitial change, the kathode from its stimulating properties is preferable. When the cause of the neuritis is not still existent, great improvement may be obtained by treatment, but not very quickly, the electrical applications must be persevered in for months, and it is surprising how much benefit will follow even where the wasting and the reaction of degeneration have been most marked. Alcoholic neuritis affects especially the extensors of the wrist and fingers, the flexors of the foot and the extensors of the toes, producing a condition of "wrist-drop" and "foot-drop" (*Buzzard*) but the neuritis is often a general one and any other parts may be affected.

225. **Paralysis of ocular muscles.**—All the various forms of paralysis of these muscles may be treated by galvanism. Occasionally from exposure to cold a paralysis of some of the ocular muscles is set up of a similar nature to the ordinary "rheumatic" facial paralysis.

Treatment is complicated by the difficulty of reaching the muscles by electricity. Their deep-seated position, the proximity of the brain and the retina, and the sensitiveness of the conjunctiva all help to make it practically impossible to excite contractions in them.

It has been proposed to use a fine electrode and introduce it into the conjunctival sac after that has been rendered insensitive by cocaine. Usually, however, good results have followed a longitudinal galvanisation of the skull, the kathode being placed stabile upon the closed eyelid. A current of 1 to 5 milliampères and a duration of 30 to 60 seconds are recommended by *Erb*. *Dr. Buzzard*[*] has recommended the use of the index finger covered by damp muslin as the active electrode (see § 189, hand electrode) or small sponges may be used. They are soft and readily adapt themselves to the surface of the eyelid. The reflex effect of faradizing the skin of the face may also be tried, as recommended for the treatment of facial paralysis. *Dr. Gowers* is of opinion that electrical treatment is of little use in the treatment of paralysis of the ocular muscles, though granting that a slight temporary increase of power may be observed after the current has been applied for a few minutes; at the same time that fact should afford grounds for hoping that benefit might follow systematic and prolonged treatment. *Dr. Buzzard* has reported two cases where permanent improvement did follow galvanism.

226. **Facial paralysis.**—This is a common form of paralysis, and very frequently comes under electrical treatment.

If we except those cases of paralysis of the facial muscles which form part of hemiplegia the remainder usually depend upon disease of the "lower segment," that is to say, of the nerve trunk and its nucleus of origin, and of these the commonest seat is in the nerve trunk.

It follows that the reaction of degeneration is likely to be present in a large number of cases of facial palsy, and a case carefully watched and treated from the commencement offers one of the best introductions to the subject of electrical diagnosis and therapeutics. In all but the slightest cases of disease of the facial nerve the faradic reaction disappears within the first ten days, often within the first week. If the patient is tested daily, the gradual diminution of faradic, and exaltation of galvanic irritability will be clearly seen. In testing the muscles it is well to bear in mind that the skin of the face is sensitive, and the muscles are near the surface, strong currents are therefore unnecessary, and must be avoided. For the importance of the electrical reactions in prognosis see § 170.

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[*] "Lancet," vol. ii., p. 485, 1875. "Brain," 1890.

The part of the nerve which is usually at fault is that which passes along the Fallopian aqueduct.

In this part a very little swelling of the nerve or of the walls of the aqueduct is sufficient to cause compression of the nerve fibres. Disease of the ear and exposure to cold are the commonest exciting causes.

The electrical treatment should be in accordance with what has been laid down for paralysis in general, viz. : galvanism to the seat of lesion, direct galvanism of the affected nerve and muscles, and reflex stimulation by faradism of the skin of the face ; treatment may be commenced at once. For reaching the seat of injury the transverse galvanization of the skull (§ 184) is advised with the electrodes behind the ear or below it, the anode stabile on the affected side. Then the nerve and muscles may be treated with the kathode, each of the main branches of the nerve being stroked in a labile manner from centre to periphery, and each muscle being treated with the same pole stabile for half a minute, while the anode remains as at first. Lastly, the skin of the face may be gently faradized with a moistened electrode. In older cases the faradization may be more vigorously applied with the metallic brush.

227. **Neuralgia.**—This morbid state offers a field as wide as it is successful to the electro-therapeutist (*Erb*).

Severe nervous pains which might fairly be called neuralgic are often present in cases of injury or disease of nerves, but in many cases of neuralgia nothing so definite can be found. *Fagge*[*] recognises two distinct affections in what is commonly called neuralgia, he thinks that one is really due to peripheral irritation, but that it is not an irritation applied to the painful nerve, so that the patient is mistaken in his interpretation of the local sign. This is sometimes called reflex neuralgia, as an instance he cites the trigeminal neuralgia so often excited by disease of a tooth. In the other form of neuralgia, of which sciatica may be taken as an example, there is every reason to believe that the morbid process begins in the trunk of the nerve which seems to be the seat of pain.

The electrical treatment of neuralgia may take either of two different directions. In the more rational one the action of the anode is brought to bear upon the seat of pain with the object of inducing a state of anelectrotonus, in the hope that its sedative effects may gradually leave a permanently soothing impression upon the nerve. In the other the principle of counter-irritation is followed, and by the production of painful cutaneous impressions it is sought to create a diversion as it were in the nature of the impulses conducted along the nerve, and so to remove its neuralgic condition. Counter-irritation is a very popular treatment for neuralgic pains, and galvanism or faradism affords a counter-irritant of great convenience in application. Electrical counter-irritation has the great advantage that it does not damage or destroy the skin in the way that blisters or the cautery do. The electrical treatment of neuralgia is not to be followed blindly. In every case which offers itself a minute and careful search should be made for any local cause or general morbid condition, and medical treatment must be brought to bear upon them when they are found. Electrical treatment is of especial value in cases where no exciting cause of the neuralgia can be discovered, or where it cannot be remedied by ordinary treatment. There are very many such cases, and electrical treatment often affords speedy relief. We have already referred to the neuralgic pains of *tabes dorsalis;* in this disease, and in other general morbid conditions such as *debility*, *anæmia*, and *hysteria*, neuralgic symptoms are common and sometimes severe, and electrical treatment should be tried.

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[*] "Principles and Practice of Medicine."

When painful points are present in a case of neuralgia they are to be attacked by the stabile action of the anode. These painful points were described by *Valleix*, and shown to correspond to spots at which the cutaneous nerves emerge from bony canals or fasciæ, but perhaps they merely signify a general tenderness of the nerve trunk, which is most manifested at those particular places where they are most subject to pressure.

228. **Trigeminal neuralgia.**—Without going into the description of the various kinds of neuralgia it may be as well to consider for a moment neuralgia of the fifth cranial nerve and sciatica. The fifth nerve is perhaps the commonest seat of neuralgia, and in very many cases its condition is one of "reflex neuralgia," the teeth in particular being very commonly at fault, next in frequency errors of refraction should be looked for. But not all cases of trigeminal neuralgia can be traced to an exciting cause, and the most severe form, known as *tic douloureux*, is often present when no source of irritation can be found. *Duchenne's* treatment for all

forms of neuralgia (except those in which some gross lesion of the nerve was present) consisted in severe faradization of the painful area after drying and powdering the skin to diminish its power of conduction. In this way he endeavoured to limit the action to the cutaneous surface. If the skin were not first dried the current penetrating the tissues to the trunk of the nerve was likely to do harm instead of good.

He reports one or two cases of severe *tic douloureux* which derived great benefit from this mode of cutaneous faradisation, but confesses that his successes were rare.

In facial neuralgia statical treatment by the pencil method (§ 95) will sometimes effect a cure. If the case is obstinate small sparks may be taken from the painful region. Daily applications should be resorted to, and in very acute attacks two or three applications may be made in one day. Tic douloureux will sometimes disappear as if by magic by simple positive charging.

The stabile action of the anode to the painful part is often of use in trigeminal neuralgia.

229. **Sciatica.**—In this complaint, treatment is much more favourable. *Duchenne* says that after the application of the dry brush the patient is astonished to find all the pain of the sciatica gone, and though he tries to provoke its return by movements of the leg and foot, it does not do so. Sometimes a single treatment dispels the sciatica completely, at other times the pain returns after a few hours of absence, and the treatment must be repeated, but cure may be expected after four or six or eight sittings.

Prognosis is good if the first treatment produces even a temporary relief from the pain.

*Steavenson** has published an account of sixty cases of sciatica treated by electrical applications, of this number thirty-seven were cured, eleven were improved, two failed, and the remainder were uncertain. The method employed was to apply the kathode labile to the back of the thigh along the course of the sciatic nerve, and over the lower portion of the spine, while the anode was placed on the abdomen. The application lasted at each séance for eight to ten minutes, and the integument over which the electrode had passed became suffused with a bright blush, the patient experiencing a glowing feeling of warmth in the same track. The stiffness of the muscles was also relieved, and the patient was able to bend down and get up from a sitting position with great ease for several hours, even after the early applications. In the galvanic treatment of neuralgic pains large electrodes should be used, it has even been proposed to use electrodes large enough if possible to cover the whole of the affected area at once (*Von Ziemssen*). Lumbago is also quickly relieved by galvanism with the anode.

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* "Lancet," Jan., 1884, July, 1886.

230. **Herpetic neuralgia.**—The severe neuralgic pain which sometimes follows an attack of *herpes zoster* is said to be readily removed by the application of the anode. See a case reported by *Erb*.*

231. **Spasm and wry neck.**—There are several forms of spasmodic muscular contraction, some tonic and some clonic, which are not uncommon. Spasm is not infrequently a reflex phenomenon, thus there may be severe spasm of the muscles of mastication from inflammation about the gums or throat, and inflamed cervical glands sometimes cause wry neck. Or there may be spasm from direct irritation of the nerves as in wry neck from disease of the cervical vertebræ.

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* "Electro-therapeutics," p. 515.

In children, and also, though less commonly, in adults, wry neck may be due to exposure to cold or wet, and this form has been called "rheumatic." Spasms are also common in hysterical and emotional people, and in such they may come on quite spontaneously or as a sequel of some slight injury. These may persist for years, and may not only simulate lateral sclerosis, but may also lead to it. Apart from hysteria we often find that spasmodic contractions have been brought on by prolonged mental anxiety or worry.

Facial spasm or histrionic spasm is not uncommon in its slighter degrees, and shows itself usually in the form of twitchings of some of the facial muscles. Sometimes the twitchings are very frequent and severe, and though at first they can be controlled by an effort, they may in time become quite uncontrollable. The commonest form of spasm, however, is wry neck or *torticollis*, tonic or clonic. The sterno-mastoid is usually at fault, but occasionally the wry neck is produced by contraction of the *splenius capitis* or the *trapezius*.

Very often no cause can be found for the wry neck, and perhaps it is most obstinate in these very cases.

Electrical treatment has been often tried for spasmodic affections, and it is very successful in some, but fails completely in others. In hysterical cases, the faradic brush or the application of static sparks may always be tried with good prospects of improvement. In the other cases galvanism is better, the stabile action of the anode being employed over the affected muscle and its nerves. *Erb* has recorded twenty cases of spasm in various muscles, almost all of which were cured by electrical treatment; a few of them improved only after a very large number of sittings, but others were very promptly cured by three or four. *Erb* also found that reversals of the current were useful in some of the cases.

232. **Writer's cramp.**—This is the best known form of a group of spasmodic affections which are produced by prolonged over-work of certain muscles, particularly when the work done is of a complicated and highly co-ordinated kind. The name of function spasms has been given to this class. Besides those whose occupation is writing, violinists, piano-players, tailors and shoemakers are said to be subject to similar spasmodic attacks in the muscles which they use most often. In writer's cramp there is a combination of muscular spasm with paralysis ; either of these may predominate, and the first and chief seat of the cramp or palsy is in the intrinsic muscles of the thumb and in the first dorsal interosseous; if the habit, writing or what not, be persevered with, other muscles are made to take the place of those which are deranged, and soon they also suffer.

Galvanism is of great value in this disease, but it must be helped by the complete abandonment of the habit which has caused its development.

*Dr. Poore** has paid great attention to the subject of writer's cramp, and advises the use of the continuous current, he places the anode in the axilla, and the kathode over the ulnar nerve just where it leaves the biceps on its way to the olecranon. The strength of current is "short of that which causes muscular contraction, but is just sufficient to make the patient conscious of a tingle in the end of the little finger when the current is made and broken." The patient is then made to exercise the interossei by separating and approximating the fingers rhythmically. Another plan recommended by the same writer is to place the anode over the median nerve at the inner border of the biceps, and the kathode over the body of the flexor longus pollicis, while the patient is made to flex rhythmically the distal phalanx of his thumb. Other similar plans including the combination of a descending current with rhythmic exercises may be used.

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* "Electricity in Medicine and Surgery," 1876. "Medico-Chirurgical Transactions," 1887.

In *Dr. Poore's* later article on writer's cramp he has shown that a good many patients have signs of some slight central lesion, either in brain or cord, the largest number do not show these signs, but many of them have altered faradic irritability in the affected muscles, and tremors and tenderness of the nerve trunks. It is possible that slight neuritis may be present in some of these patients.

In the "*Centralblatt fur die gesamm. Therap.*," Ap., 1891, *Max Weiss* discusses the electrical treatment of writer's cramp, and points out that three conditions may be found in these cases, (1) spasms, (2) tremors, (3) paralyses, and sometimes there are combinations of more than one of these morbid states. In the spasmodic cases, which are usually tonic rather than clonic, on taking up the pen, the thumb, index and middle fingers, and especially the thumb and index pass into a state of tonic spasm; the *opponens pollicis* and the *flexor proprius pollicis*, and the long flexors and *interossei* and *lumbricales* all share in the spasm. The extensors are less commonly thrown into spasm, the *flexor* and *extensor carpi ulnaris* may share it. Pronation and supination are seldom affected. Further, there is pain in the ulnar and median areas, tender points in the arms on both anterior and posterior aspects, and at the spinous processes.

The disturbances are situated in the median and ulnar nerves, not in the motor cortex nor in the spinal cord. The treatment recommended is the use of constant currents of from two to five or eight milliampères for fifteen to twenty-five minutes with absolute rest from writing; galvanize twice daily during the first weeks, afterwards diminishing to two or three times a week. Anode in the palm if extension is the main symptom, on the dorsum if flexion. Kathode to be placed on the nape of the neck, or on the upper and inner part of the arm. Anode may also be applied to the tender points for ten to twenty minutes.

In *paralytic cases*, galvano-faradization with a roller electrode followed by the anode labile to the affected muscles is advised. For *tremors* of the affected muscles the same procedure should be adopted.

233. **Tetany.**—This form of spasm, although not very common, deserves mention here, because of the peculiar increase in electrical irritability which forms one of its leading symptoms. There is also, as is well known, an increased irritability of the nerves and muscles to mechanical stimulation, and this is not confined to any particular nerve, although it has been most commonly observed in the facial nerve (facial irritability). The peculiar spasms can be evoked by compression of a nerve trunk or of a main artery of a limb (*Trousseau*), or by a rough touch over a motor nerve. *Erb*[*] first showed that the electrical irritability was also increased in this disease.

In a recent paper *Dr. Bernhardt*[†] has reported three cases in which the electrical reactions were examined, his results compared with the normal irritability of the same nerves are represented in the following table, which gives the current in milliampères required to produce the first contraction, KCC.

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[*] "Arch. f. psychiatrie," 1874, § 271.

[†] "Berlin. Klin. Wochenschrift," June 1891, No. 26.

NERVE.	NORMAL.	TETANY. 3 CASES.
Facial	0·9—3 milliampères	0·5 —1·5 milliampères
Median . . .	0·9—3·3 ,,	0·25—1·5 ,,
Musculo-spiral .	2· —5 ,,	0·25—1· ,,
Peroneal . . .	1· —2 ,,	0·5 —1·1 ,,

KDT (kathodal duration tetanus) and ACC were also more easily produced than usual. AOT (anodal opening tetanus) which is a most uncommon reaction, was also observed in one of the cases. The irritability to faradism was likewise increased in all three patients. In the electrical treatment of tetany the influence of the anode stabile is to be directed to the affected parts, and the current must be gradually diminished at the termination of the sitting to avoid the ill effect of the anodal opening (compare § 211). The results of treatment are said to be entirely favourable.

234. **Anæsthesia.**—The treatment of anæsthesia is similar to that used for paralysis. The cerebral anæsthesia which sometimes occurs with hemiplegia is usually not permanent, and it may very often be made to disappear by a few applications of the faradic brush to the affected areas. Hysterical anæsthesia is also easily dispelled in the same way.

When paralysis and anæsthesia coexist from disease of the spinal cord or spinal nerves, the prognosis and the treatment are similar for both. Very often the anæsthesia is much less marked than the paralysis, and it recovers more quickly in the favourable cases.

Anæsthesia of the sensory portions of the trigeminus has also been observed, see *Erb*, "Electro-therapeutics," p. 572. *Fagge* quotes from *Romberg* a case which came on after exposure to cold, and might therefore be of a similar nature to the cases of facial paralysis produced in the same way. Serious disease in the neighbourhood of the Gasserian ganglion may also produce anæsthesia of the face.

235. **Anosmia.**—A case of anosmia has recently been under treatment in the electrical department at St. Bartholomew's Hospital, with a satisfactory result. The patient was a woman in whom the loss of smell had come on as a result of injury. After twenty sittings the sense of smell returned, so that she could easily recognise the smell of onions. The treatment followed was galvanism stabile, the anode to the mastoid processes, the kathode to the root of the nose for ten minutes twice a week.

Dr. Wahltuch ("Brit. Med. Journal," Sept. 1883), has reported a case of loss of taste and smell for five months after a severe cold. Galvanism applied to the nose and tongue effected a cure after six sittings.

236. **Optic neuritis and atrophy.**—Galvanism has also been used for optic atrophy and optic neuritis, several cases have been reported in which improvement of sight has followed. When atrophy comes on without previous optic neuritis, the prospects are considered less favourable. The treatment is (1) transverse galvanization through the temples with reversals; (2) longitudinal through the head, the anode over the closed eyelids. For a full account of the treatment, with reports of eight cases by different observers, see *Erb*.*

237. **Auditory nerve deafness.**—The treatment

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* "Electro-therapeutics."

already described (§ 211) as suitable for tinnitus aurium may also be followed in cases of nervous deafness. *Althaus* and others have reported successful cases.

Statical treatment by sparks may be applied to the meatus and to the tympanic membrane by means of a special form of spark regulator (§ 93) fixed in a vulcanite speculum. Sometimes the results of statical treatment are very satisfactory.

238. **Muscular atrophy.**—Apart from the atrophy of muscles which follows disease of the nerves, or of the anterior cornua of the cord, there are cases where the morbid process is limited to the muscles. Thus, a muscle may waste from disuse, especially when the disuse is secondary to joint disease; such a state of things occurs in the deltoid, not uncommonly also in the extensors of the leg, after affections of the knee joint.

The electrical reactions in these cases are natural, or there may be slight qualitative diminution, there is no reaction of degeneration.

There is also another group of muscular atrophies which has been called "idiopathic," where there is extensive wasting of muscles, but no changes are to be found in the cord or nerves. The best known of these is pseudo-hypertrophic paralysis, here in the early stages the atrophy is masked by the deposition of much adipose tissue in the place of the muscle fibres. In other forms of myopathic atrophy there may be no such deposition of fat, and the size of the muscles may shrink from the first. They are often hereditary, and may occur in several members of a family. There is no reaction of degeneration, but only a simple diminution to galvanism and faradism. Not much good results have been obtained from electrical treatment; galvanism with weak currents and regular faradization have been recommended and may be tried.

CHAPTER XIV.

Other Conditions requiring Electrical Treatment.

Joint affections. Sprains. Myalgia. Ascites. Constipation. Galactagogue effects. Nocturnal enuresis. Weakness of the bladder and incontinence. Morbid sexual states. Diseases of women. In childbirth. Amenorrhœa. Chronic metritis and subinvolution. Uterine neuralgia. Arrest of growth of cancers. Healing of chronic ulcers. Guinea worm. Test of death.

239. **Affections of the joints.**—A considerable amount of attention has been given to the electrical treatment of joint affections. *Dr. Danion*[*] has found brisk faradism with the metallic brush to be a valuable treatment in the inflamed and tender joints of acute rheumatism; he reports that much relief to the pain and tenderness follows at once, strong currents are well borne, and the presence of fever is not a contra-indication to their use. *Drosdoff*,[†] quoted by *Erb*, makes similar statements, he found that the sensitiveness to faradic currents was much lowered over the affected joints, and that treatment daily for five to ten minutes reduced the pain considerably, lowered the temperature of the joint, and shortened the course of the case. He employed moist electrodes in preference to the dry brush. This treatment might very well be tried in cases which do not respond satisfactorily to salicylates,

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[*] "Traitement des affections articulaires par l'Electricité," Paris, 1887.

[†] Cent. f. d. Med. Wissensch., 1875, 17.

or when the patients are suffering much distress from the joint pains.

Danion also mentions that he has obtained favourable results with faradism in acute gouty arthritis.

In chronic joint affections also both the galvanic and faradic currents have been used, the former should be preferred. Occasionally a single joint may remain damaged after acute rheumatism, when the other joints have recovered, or several joints may be left in a crippled state. These are to be treated by strong continuous currents, with large soft electrodes applied one to each side of the affected part, and with reversals occasionally. Effusions (hydrops articuli) are quickly lessened, and the pain or stiffness are dispelled after ten or twelve sittings. If the muscles round the joint show a tendency to wasting they must not be neglected, but must also receive treatment with the kathode.

The same treatment is to be tried when the joint has become stiff from disuse, long bandaging, or old injury.

240. **Sprains and dislocations.**—Here the continuous current is the best application, both poles are to be placed on the affected part, large electrodes. *Remak* has reported cases of cure following the application of the current from fifty *Daniell's* cells to sprained joints. The pain, the swelling, and the discolouration all quickly disappear, and in the course of a few days or a week the parts are well. *Danion* prefers faradization, and has met with good results from its use.

241. **Rheumatoid arthritis.**—The treatment of this condition by the electric bath has already been fully described. The bath is the most convenient and satisfactory mode of treatment, especially when combined with direct galvanization of the finger joints as there laid down. The warm water no doubt exercises in

itself a considerable influence. The use of the constant current without the bath may also be practised. Although several writers report favourably on this *dry* galvanic treatment *Erb* does not consider that he has seen it produce much benefit. He is of opinion that treatment should include both the affected joints, and also the central nervous system (spinal cord, cervical sympathetic).

242. **Myalgia.**—This is the name given to those pains which are felt in over-fatigued muscles; when patients are in a condition of debility, so trifling an amount of muscular exertion may be enough to produce these myalgic pains, that the connection between them and their true cause may be entirely overlooked. Hence myalgia is constantly confounded with hysterical, rheumatic, spinal, and other diseases.* The symptoms are pain in the muscles, made worse on movement, and tenderness. The skin over the muscles may also be very tender. The pains are often referred to one of the tendinous insertions of the affected muscle, and the trunk muscles are most commonly affected. *Dr. Inman* mentions as common seats of myalgic pain (1) the trapezius at its insertion into the occipital bone and into the spine of scapula; (2) the spines of the dorsal and lumbar vertebræ (origins of spinal muscles); (3) the front of the chest (origin of pectoralis major and minor) producing infra-mammary pain; (4) at the margins of the ribs, or at the pubes (insertions of recti abdominis).

Myalgia may exist in persons who are apparently healthy, and it may be difficult to decide what is the particular cause of the muscular fatigue which they suffer from; at the same time their pains may be very obstinate and very troublesome, and may resist all treatment until the diagnosis is clearly established, and rest for the affected muscles can be contrived. The movements which specially aggravate the pain must be carefully ascertained in order to decide upon the exact muscle which is at fault. Galvanism may so improve the tone of the muscles as to enable them to perform without fatigue the work they are called upon to do. Large electrodes and powerful currents, 20 to 40 milliampères, are to be used, the anode to the painful parts, the sitting may be terminated by a few reversals. This is the method advised by *Erb*. He also mentions that vigorous faradization to throw the muscles into powerful and repeated contractions is sometimes useful.

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* *Inman* on "Myalgia," *Churchill*, 1860.

243. **Ascites.**—Several writers have reported favourably of the treatment of ascites by faradization of the abdomen. The application should be applied energetically for fifteen or twenty minutes so as to set up vigorous and repeated contractions of the muscular walls of the abdomen. As a consequence the urine is increased and the ascites tends to disappear. The prospects of permanent cure of course depend upon the cause of the ascites in each particular case.

244. **Constipation.**—Peristalsis can be set up by faradization applied through the abdominal walls, and the tendency to chronic constipation can be permanently remedied by its use. The poles may be placed one on the lumbar spine and the other on the surface of the abdomen, they should be of large size; the abdominal electrode should be moved over the whole surface of the belly for a period of five or ten minutes. After a few applications the bowels become more regular. *Dr. Wahltuch*[*] reports seven cases in which the continuous current produced good results. His method was to use

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[*] "Brit. Med. Journal," 1883, ii., 623.

a large sponge for the positive pole, and an ordinary medium sized negative electrode. The former was applied to the epigastrium, while the latter was slowly moved over the whole abdominal surface, "in the direction of the intestinal canal from the duodenum to the sigmoid flexure," where it was finally fixed, and the current of from five to thirty Leclanché cells allowed to pass steadily without interruption for ten, twenty, or thirty minutes. The operation was repeated every other day for periods of from three to six weeks. The bowels gradually became regular in their action, although all aperients and enemata were stopped, and they remained so after the cessation of the treatment.

Another plan for obstinate cases is to introduce a bougie electrode (fig. 80) into the rectum, the other pole being kept on the abdomen as before, the faradic current should be employed to avoid risk of setting up ulceration and soreness of the rectal mucous membrane.

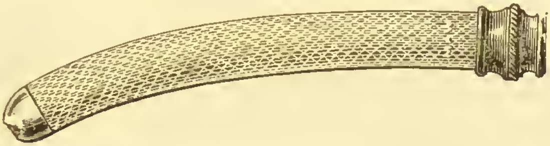

FIG. 80.—Rectal bougie electrode.

245. **Galactagogue effects.**—Faradism applied to the mammary glands has been found most useful for promoting the secretion of milk. *M. Pierron*[*] declared that faradism has so powerful an influence upon the mammary gland that he believes that even the breasts of virgins might be made to yield milk in this way. He applies one electrode (cup-shaped) over the papilla, and

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[*] "Brit. Med. Journal," 1887, i., p. 799.

moves the other over the different parts of the gland. Other cases are quoted by *Drs. Beard* and *Rockwell.*

246. **The urinary organs.**[*]—The results obtained by the electrical treatment of nocturnal incontinence in children is very favourable. By placing one electrode over the lower dorsal spine, and the other on the perineum, the whole nervous supply of the bladder can be included in the circuit. In addition to the cases which are due to phimosis, reflex irritation from worms and oxaluria, there are many others in which during sleep the inhibitory influence of the higher centres appears to be in abeyance, and any accumulation of urine in the bladder excites a reflex contraction of its walls, and consequent expulsion of the urine. These cases are readily cured by galvanism, it is seldom necessary to introduce the electrode into the bladder; the best plan of treatment is to place the indifferent electrode upon the lower dorsal spine, and the active electrode (positive) to the perineum, a small button-shaped electrode is most convenient. The perineum is a sensitive region, and strong currents should not be employed, the small area of the perineum, especially in females, makes it necessary that the electrode should be in one place during the whole of the application, and with a small electrode there would be risk of electrolytic effects if large currents were used. The figure (fig. 81)

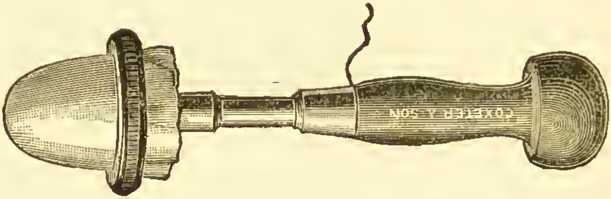

FIG. 81.—Electrode for enuresis.

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[*] *Dr. W. E. Steavenson* in "Brit. Med. Journal," Nov. 1886.

shows an electrode of suitable shape. It is contrived so that the washleather cover can be changed in a moment. The ring of vulcanite is pushed on over the piece of washleather and holds it in place.

In cases of simple incontinence of urine, when the sphincter is not at fault, and when the affection is due to the loss of the power of inhibition during sleep, or to paralysis of the muscular coats of the bladder from over-distension or other causes, then one electrode may be placed over the pubes. But in cases where there is weakness of the sphincter, unless an electrode is placed in the urethra itself, no doubt the most advantageous place for the second electrode is the perineum. The tendency of all electrical currents is to take the shortest route possible to complete the circuit, always, of course, choosing the road offering the least resistance. If one electrode be placed on the lower dorsal spine, and the other above the pubes, the sphincter vesicæ is almost completely without the circuit, and then receives very little direct influence. I have known electricity so applied in the case of females, from feelings of delicacy, when the sphincter vesicæ was no doubt at fault. If the current is not applied directly to the part affected, it is best to dispense with electrical treatment altogether, for it most assuredly will fail.

Many of the cases I have had have been in females where the sphincter was no doubt at fault. In one case sent to me by *Dr. Matthews Duncan*, the urethra had been dilated to explore the interior of the bladder. This was followed by incontinence. Another woman, after a difficult labour, always had incontinence in the erect position. This case was cured by galvanism. I have had several patients who have been unable to retain their urine when making the slightest extraordinary exertion, such as going upstairs, lifting weights, and even when laughing or crying. I do not remember any of these cases which have not been cured by electricity. I am not including cases of old women, in whom violent bronchitic cough is so often accompanied by an escape of urine, although these cases no doubt might be improved.

Undue frequency of micturition is also relieved by galvanism, possibly by strengthening the nervous supply of the bladder so that the reflex act is not so readily induced. When this undue frequency is caused by cystitis, I believe that relief is effected by a healthier condition of the walls of the bladder being induced by the current. I have had several cases of cystitis sent to me, and they all improved; some have been cured. One or two of these cases I have treated in conjunction with *Mr. Bruce Clarke.* In the application of electricity to the bladder for atony, incontinence, or frequency of micturition, I have usually employed the current for about eight or ten minutes every day or every other day, the greater majority of cases only requiring it about eight times. A sound insulated, except at the extremity, is passed into the bladder. The strength of the current used has been from two to three milliampères up to five if the patient could bear it. Another affection connected with the urinary organs which can be relieved by galvanism is neuralgia of the pudic nerve. I have had one or two cases of the kind, and one was described a short time ago in the "Lancet," 1886, vol. ii., p. 181. The affection is associated with severe pain in the perineum, often periodic, and increased by walking; it is sometimes accompanied by a painful spasm of the urethra whenever an attempt is made to pass water. The pain sometimes extends beyond the perineum into the groin. The constant current applied in the same way as for incontinence of urine will generally relieve the pain after a few applications.—

For many of the cases of bladder weakness in children and young adults faradism applied in the same way acts almost, if not quite, as well as galvanism.

In retention of urine occurring in hysterical subjects one pole, not insulated, may be passed into the urethra and bladder, and faradism applied, care being taken to strengthen the current very gradually.

247. **Sexual disorders.**—Various morbid sexual conditions have been treated by electricity. The nervous supply of these organs is almost identical in position with that of the bladder and rectum, and the seat of application is somewhat similar in both cases. The galvanic current is usually the best to employ.

A small button-shaped electrode connected with the positive pole is held to the perineum, and another larger electrode (negative) is moved slowly up and down the lower dorsal and lumbar spine. The current may be from 5 to 10 milliampères according to the tolerance of the patient, and the time occupied may be ten minutes. Applications daily for a week, then every other day. In this way the symptoms may be dispelled. Continence must be enjoined during the treatment. The penis and scrotum have also been faradized with the dry brush for impotence and sexual debility.

248. **Diseases of women.**—Electrical methods are largely made use of in gynæcological practice, not only for the sake of obtaining the direct effects (stimulating, sedative or trophic) of electricity, but also for electrolysis, and the galvano-cautery (see Chapters XV., XVI.). Much attention has been directed to the subject of the electrical treatment of fibro-myoma, and an immense

amount of literature has been produced since the introduction of *Dr. Apostoli's* method of treating that complaint by electrolysis of the uterine mucous membrane. His methods and results will be fully dealt with in the next chapter.

249. **In parturition.**—In a paper read by *Dr. Kilner* before the Obstetrical Society,* the use of the faradic current is advocated during parturition. He found that uterine contractions could be excited or strengthened by its aid, though not in all cases. Sometimes the resulting contractions were very severe and prolonged, indicating possible risk to the child. The faradism seemed to diminish the pains felt during the labour. After the birth of the child faradic stimulation ensured a firm uterine contraction, and much diminished the risk of post-partum hæmorrhage. Some medical men speak very highly of its value in childbirth, and make a practice of carrying a small faradic apparatus in their obstetric bag. It has also been of great use in flooding after miscarriage.

It follows that great caution should be used before applying electrical treatment to the abdomen or pelvic organs of a pregnant woman. Cases have been reported where a miscarriage has been the result of faradism, or of the Leyden jar shocks used by *Dr. Golding Bird*, although this result is not an invariable one.†

250. **Amenorrhœa.**—Electricity has been employed in the treatment of this condition since its first introduction into medicine more than a hundred years ago. *Dr. Golding Bird* had a very high opinion of the value of shocks from the Leyden jar for curing this symptom.

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* "British Medical Journal," April, 1884.

† *Golding Bird*, "Electricity and Magnetism," 1849, Lect. v., and Appendix B.

He says "in electricity we possess the only really direct emmenagogue with which the experience of our profession has furnished us." His method was to transmit through the pelvis twelve shocks in succession from a Leyden jar capable of holding about a pint measure, the discharge was directed from the sacrum to the pubes by means of conductors. Faradism applied to the uterus has also been found efficacious in patients with amenorrhœa from sluggishness of the uterine functions apart from chlorosis. When this condition is present general treatment is sufficient, and local applications are not called for, and indeed are undesirable. In healthy women in whom menstruation is regularly performed galvanism or faradism will sometimes hasten the appearance of the flow, especially when it is applied to the abdomen or pelvic region. The electric bath may have the same effect.

It is best to suspend treatment in women during the menstrual periods, otherwise the flow may be rendered excessive, and in pregnancy it is better not to employ electricity at all for abdominal or bladder troubles.

Although electrical treatment in the healthy may produce or accelerate menstruation, it will not always do so when that function is in abeyance. The best results in this condition as in others are obtained by localising the treatment to the affected parts by the direct application of the electrode to the cervix uteri, although in the unmarried it is usually sufficient to place one pole on the perineum and the other over the sacrum or the pubes with the same precautions and in the same manner as advised for incontinence of urine. Faradization is the best method; an electrode in the form of a bougie insulated except at its extremity is to be employed. *Apostoli* has advocated the use of a bipolar electrode for faradism of the uterus, but it is not always so satisfactory as the unipolar method, the current sometimes passes directly across from pole to pole at the extremity of the double electrode, without diffusing itself at all through the tissues in the neighbourhood.

251. **Subinvolution.**—*Dr. Grandin*, quoted by *Dr. Bigelow*, recommends the treatment of this condition by faradization of the uterus. Its application to the enlarged, flaccid and congested organ produces contraction of the muscular fibres, improves the tone of the whole uterus, diminishes the congestion, and leads to diminution in its size. The method seems to be rational, and is supported by *Apostoli* in a paper translated and published in the "British Medical Journal," Jan. 14th, 1888.[*] There, after discussing *Tripier's* introduction of faradism as a remedy for uterine inertia, he advocates the use of a bipolar electrode (fig. 82) introduced into the vagina or the uterine cavity in place of the unipolar method (utero-sus-pubic) employed by his predecessor. The secondary coil of thin wire,

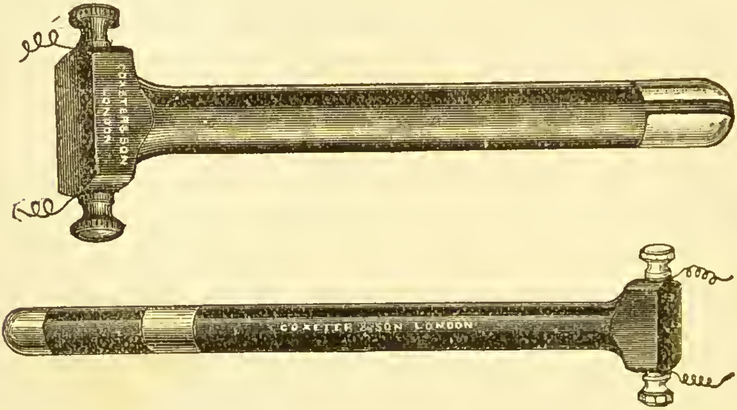

FIG. 82.—Bipolar electrodes.

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[*] On some new applications of the faradic current in gynæcology.

"current of tension," is recommended, on the ground that the current of high tension is less painful than the "current of quantity" from a short thick secondary wire. We have already given a reason for preferring the unipolar method.

252. **Uterine neuralgia.**—The use of faradism for the relief of painful affections of the pelvic organs in women has been already alluded to. It is important for this purpose to make use of faradic currents of rapid frequency. The slowly interrupted faradic current produces much more painful sensations than those of a rapidly acting instrument, but by suitably choosing the rate of interruption of the current, a soothing or benumbing effect can readily be produced.

The anode of the continuous current may be applied over the region of the ovaries for tenderness and pain in that situation.

253. **Treatment of cancer.**—In the "British Medical Journal" for 1889, vol. i., pp. 936, 1288, *Dr. Inglis Parsons* has published an account of "Arrest of growth in four cases of cancer by a powerful interrupted voltaic current."* *Dr. Parsons* advances a theory that it may be possible to destroy the vitality of cells by powerful galvanic shocks, and lays stress on the known fact that malignant growths are prone to break down and degenerate, and may therefore be of a lower vitality than the cells of healthy tissues. He then recounts the cases in which he has tried to kill the cancer cells without destroying the parts in which they were situated, by introducing a number of fine needles all round the growth, and passing through it a galvanic current with sudden interruptions. Commencing with ten, the current is gradually raised as high as 600 milliampères "flashed

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* See also "Medical Press and Circular," December, 1890.

through the growth in every direction from 50 to 100 times." The effects said to be produced are: "a cessation of growth, gradual disappearance of pain, some shrinking and hardening of the tumour and enlarged glands, followed by improved nutrition and better state of the general health. The growth as a whole does not disappear, but remains as an inert mass, composed in all probability of fibrous tissue only."

254. **The healing of chronic ulcers.**—This was the subject of a communication to the Medico-Chirurgical Society in 1848 by *Sir Spencer* (then *Mr.*) *Wells.* A simple galvanic element made up of a plate of silver and one of zinc, connected together by a wire and applied to an ulcer, were found to promote cicatrization at the part in contact with the silver, while that part which touched the zinc plate became worse. It would, perhaps, be profitable to repeat the experiment, while endeavouring to minimise the unfavourable action at the zinc plate by largely increasing its surface, and placing it upon a sound part of the skin.

Daily faradization of an indolent ulcer for ten minutes will sometimes improve its condition and promote healthy action.*

255. **Guinea worm.**—In the "British Medical Journal" (1883, vol. ii.), an account of the removal of a guinea worm with the aid of galvanism was published by *Mr. Alexander Faulkner.*

One pole of a battery was held in the patient's hand, and the other was applied to the protruding extremity of the worm, the application was continued for an hour with gentle traction, and at the end of that time the whole had been extracted: the usual process of withdrawing the guinea worm little by little by traction for a few minutes daily is a very tedious affair, and may take weeks to complete it, even if the worm is not broken in the process. *Mr. Faulkner's* explanation of the action of the galvanism is that the worm is benumbed and rendered incapable of resisting.

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* *Beard and Rockwell.*

256. **Electricity as a test of death.**—The electrical reactions of muscle to faradism have been proposed as a test of death. The contractility of living muscle persists for a few hours after death, and then disappears.

If the muscles of a person supposed to be dead cannot be caused to contract by a strong faradic current, life may be considered extinct, if they do contract it is possible that he may be alive. Certainly no person should be buried if his muscles are still contractile.

Onimus and *Legros*[*] have shown that there is a stage in the death of a muscle at which it gives the reaction of degeneration, that is to say, the faradic irritability disappears first, while the response to direct galvanic stimulation continues, giving rise to a *sluggish* contraction. This change sets in about four hours after death, and they relate a case in which the reaction enabled them to specify correctly the time at which death had occurred.

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[*] "Traité d'Electricité Médicale," Paris, 1888.

CHAPTER XV.

ELECTROLYSIS.

THE laws of electrolysis. Secondary reactions. Action in the interpolar region. Migration of the ions. Osmosis. Actions in living tissues. Uses in surgery. Removal of hairs. Hairy moles. Warts. Nævus. Port wine mark. Aneurysm. Stricture of the urethra, of the œsophagus, of the rectum, of the Eustachian tube. Stenosis of the cervix uteri. Electrolysis in fibro-myoma. Dr. Apostoli's methods. Extra-uterine fœtation. Cancer.

257. **Electrolysis.**—The laws according to which substances are broken up by the passage of the electric current, and the terms used in considering the portion of a circuit in which electrolysis is occurring were shortly given in §§ 58-60. It is necessary here to expand what was then said a little. The hypothesis of *Grotthus* was explained in § 59, according to which the molecules are arranged owing to the directive action of current in lines between the anode and kathode, and all along this line a continual decomposition and recombination takes place, which, however, is only manifested at the poles under ordinary circumstances. It is perhaps better to look on an electrolyte with *Clausius*, as a body whose molecules are continually undergoing dissociation and recombination, even when no current is passing. When, however, an electric stress is set up, there is a directive force brought to bear upon the molecules that are in a free state, and a migration is set up, the electronegative ions passing towards the anode, the electro-

positive ones towards the kathode; if the electric stress is sufficient to overcome the tendency of the dissociated molecules to recombine, decomposition takes place. Put crudely according to this view, the least electromotive force that will produce decomposition in an electrolyte is a measure of the chemical affinity of the ions in that electrolyte.

258. **Secondary reactions.**—It is but rarely that the actual products of electrolysis are given off at the electrodes, in general they react with a further portion of the electrolyte or of the solvent, or with the substance of the electrodes, and the products of this secondary reaction appear. Thus, for example, if a solution of sodium sulphate be submitted to electrolysis between platinum electrodes, the ions are sodium and the radical SO_4, but the former instantly decomposes the water present, giving off an equivalent quantity of hydrogen, while the latter breaks up into SO_3, sulphur trioxide, which combines with water to form sulphuric acid, and oxygen, which is given off. The result is that the liquid about the anode becomes acid, while that at the kathode is alkaline. Of course, if the whole is allowed to mix, the two neutralise each other, and the whole effect of the electrolysis is that some water has been decomposed.

If the electrodes consist of metals that are capable of being acted on by the ions action will take place, thus if copper sulphate is electrolysed between platinum electrodes the kathode will be found to be alloyed with the copper which will penetrate a considerable depth into the platinum (*Gore*). The anodes will be dissolved if the anion is capable of forming a salt with them, thus a platinum anode is rapidly dissolved if used to electrolyse a chloride.

Many curious secondary reactions may occur when mixed electrolytes are submitted to electrolysis, and these have been shown to vary with the density of the current used. In general the most electro-negative ion of the mixture makes its appearance first, but it has been shown experimentally by *Hittorf* that all electrolytes present are concerned.

259. **Action between the poles.**—If porous semipermeable partitions be placed between the electrodes, electrolysis will go on just as before, but by the help of such partitions it is possible to use a series of electrolytes and to examine the reactions at the boundaries of each. A strong proof is then given of the accuracy of the laws of electrolysis quoted in § 60. *Faraday* succeeded by this method in precipitating magnesia from a solution of sulphate of magnesia. He caused an electric current to pass through a solution of the salt to an electrode immersed in water, and at the boundary between the two liquids there was a precipitate of magnesia when the current passed from the salt solution to the water. Considerations of this sort may perhaps help to explain the action of a continuous current on the tissues of the body.

260. **Migration of the ions—osmosis.**—It is found when electrolysis is taking place in a solution that the strength of the solution round the electrodes varies during the course of the electrolysis. For example, if a solution of copper sulphate be electrolysed the solution round the kathode is weakened much faster than that round the anode, and so there is an effect as if the copper sulphate in solution had moved bodily towards the anode. This effect differs for different salts, and also according to the strength of the solution undergoing electrolysis. A fairly full account of a theory

which has lately been put forward to explain it and other effects will be found in *Ostwald's* "Outlines of General Chemistry," Book ix., Chapter iv. It is clear, however, that whatever the cause, the effect is likely to be of some importance in the electrolysis of living tissues which may be looked on as a mass of semi-permeable cells filled with a solution of several electrolytes. Sodium chloride, for example, is one of these, and it behaves similarly to copper sulphate, electrolysis will therefore effect a transference of the sodium chloride in the line of flow of the current towards the anode. There is another action that takes place during electrolysis which results in a transference of the electrolyte. This has already been referred to (§ 153) as electrical osmosis. In general, if electrolysis is taking place across a porous partition, there is a transference of the electrolyte in the direction of the current, viz., towards the kathode. This is most noticeable in cases of electrolytes whose conductivity is poor.

261. **Electrolysis of living tissues.**—To sum up then, we should expect to find effects produced by the electric current in passing through the body chiefly at the points of contact, viz., the electrodes. These are local effects due to the chemical action of the substances set free by primary or secondary reactions in the electrolysis. Probably we may say that in all cases with which the medical man is concerned the local effects are due to the secondary production of acids or oxidizing agents at the anode, alkalies or reducing agents at the kathode. These may be complicated by solution of the anode if it is made of a metal that forms a soluble chloride. Smaller effects may be looked for throughout the body due to chemical action between different electrolytes separated by cell walls or other

semi-permeable septa, migration of the ions, or transference of the electrolytes due to electrical osmosis. It is easily seen, however, that all these three effects will be small with such currents as are used in treatment, and probably infinitesimal.

In a communication to the "Lancet," December, 1890, on "The Electrolysis of Animal Tissues," *Dr. G. N. Stewart* gives a summary of his investigations, he found that "practically the whole of the conduction through animal tissues is electrolytic, and that the electrolytes are the inorganic constituents; when a tissue is electrolysed almost the whole current passes by the salts; the changes produced in the proteids (coagulation, formation of acid and alkali albumen) must therefore be brought about by secondary electrolytic actions. Striking changes in the distribution of the salts were produced, changes sufficient, if produced within the body, to modify nutrition profoundly. The antiseptic action of the current was studied in the case of ordinary putrefactive organisms, and it was shown that it is chiefly, if not entirely, around the anode that this action takes place."

Briefly stated,* in the electrolysis of animal tissues, a double decomposition takes place. The salts contained in the tissues split up, the alkalies are liberated at the kathode, and the acids at the anode. The alkaline metals, potassium and sodium, from their great affinity for oxygen, decompose the water in the neighbourhood of the kathode, liberating the hydrogen, which appears as bubbles of gas. The caustic potash or soda thus produced saponifies the animal tissues just as when applied in the ordinary way, and produces a soft deliquescent eschar, which is said to heal with less contraction than an eschar produced by either a wound, a burn, or an acid, and, therefore, is the most suitable to obtain when it is particularly necessary that the least possible contraction shall subsequently take place. The acids from the salts contained in the animal tissues are liberated at the anode; generally oxygen is liberated, but the reaction which takes place at the anode depends very much upon its composition. If the electrode is made of zinc, chloride of zinc is formed, which exerts its own specific action on the tissues, in addition to the oxidising effect of the liberated oxygen. The eschar formed at the anode is hard and comparatively dry; it is more limited, and the destruction of the tissues more complete; the part decomposed is, therefore, thrown off as a dry scab, and very little or no suppuration takes place. The eschar produced by the kathode is different. In its case, the caustic effects extend to a slightly wider area, are more intense the closer to the electrode, and the outer limits of the affected area are not so thoroughly destroyed, and sometimes when a too strong current has been used, suppuration takes place, and more or less tissue sloughs away, in addition to that destroyed by the electrolysis, necessarily leaving rather a more prominent scar than is left when the anode alone is used. For the destruction of small growths on the face, or on parts where it is an object to leave as little mark as possible, it is, therefore, safer to employ only the anode. The part required is then quite destroyed, shrivels up, and becomes a scab, and healing proceeds beneath it. At the separation of the scab, the skin is left only a little whiter than the surrounding texture, and this difference in colour soon ceases to be noticeable. In a mucous membrane like the urethra, where it is impossible for healing to proceed beneath a scab, it is found that, with the anode, a sore is produced which gives rise to a tougher and more contractile cicatrix than when the negative pole is employed. There are other objections to using the anode in the electrolysis of strictures. The decomposition which takes place at the anode is also modified by the substance of which it is composed. The electrode itself is partly dissolved, and enters into the new combination of elements. Some of the metal would, therefore, become oxidised, and remain in the urethra, and the electrode would become so glued to the tissues that it would not be removed without violence. In the electrolysis of aneurysms, the oxidation of the metal forming the anodal electrode is, no doubt, an advantage, as, in addition to the coagulating effect of the positive pole, if a steel needle be used, there will also be a formation of chloride of iron which possibly assists the coagulation. At the negative pole, the hydrogen or alkalies liberated in its neighbourhood have no corrosive effect upon metals, so that if an electrode be kept negative, no oxidation will take place, and when it is withdrawn from the urethra, it will be as bright as when introduced.

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* *Dr. W. E. Steavenson* in "Brit. Med. Journal," Nov. 27th, 1886.

The caustic effect of an electrode connected with the negative pole of a battery has these advantages over the use of the ordinary caustic soda or potash. As pointed out by *Dr. Poore*, it can be applied to parts difficult of access, as the male urethra or uterine cervical canal. It can be applied to these regions and others, such as the larynx, pharynx, or nasal duct, where the application of other caustics is attended with a certain amount of danger. Its effects can be limited to the points touched by the electrode. The caustic effect can be arrested, or not commenced, until the applicator, in the form of the electrode, is *in situ*, and the duration and extent of the caustic action is entirely under the control of the will of the operator.

262. **Uses in surgery.**—Electrolysis is used in surgery as a means for producing destruction of tissue in a simple and *minutely localised* manner. This is effected indirectly by the action of the chemical bodies liberated at the poles during the passage of the current. As these bodies are different at the two poles, so the actions which take place at the poles differ from one another to a certain extent. The advantages of being able to localise the effects so precisely is well seen in the operation for the removal of hairs, for here the destructive effects are confined to such a minute area in the immediate neighbourhood of the hair follicle that no perceptible scar is produced although the hair follicle is eradicated. Electrolysis has been used for the following purposes:—(1). The removal of superfluous hairs, of moles and of warts. (2). Destruction of nævi, and removal of port wine marks. (3). Coagulation of blood in aneurysms. (4). Destruction of strictures in the urethra, lachrymal canals, œsophagus, rectum, and Eustachian tube. (5). Destruction of the fœtus in extra-uterine gestation. (6). Destruction of cancerous growths; and (7) for the relief of symptoms in fibro-myoma of the uterus. This last is brought about as a secondary process which has been found to follow electrolytic destruction of the uterine mucous membrane.

263. **The removal of hairs.**—If a fine needle connected to the negative pole of a battery of four or five cells be introduced by the side of a hair and the circuit be then closed, electrolysis takes place round the needle, and the hair follicle is destroyed by the alkali produced; the hair can then be removed easily and does not grow again.

The method of operating is as follows:—The patient should recline in a good light. Having placed the indifferent electrode (anode) in contact with a convenient part of the patient's body, the kathode is attached to a fine needle set in a handle, the current collector is turned on to take up about five cells into circuit, the operator then pinches up the skin round the hair with his left finger and thumb and introduces the needle as closely as possible to the root of the hair, holding it in the proper direction for it to enter the follicle, the needle passes down readily to the required distance, about a tenth of an inch, a current of about five milliampères passes, and slight effervescence is seen at the orifice of the follicle, and at the end of ten seconds or so the needle is withdrawn. As a rule the hair can then be easily lifted out by a fine forceps; if it still remains firm, the needle must be introduced a second time until it is loosened; the current should be just strong enough to produce slight frothing. The best way to learn how to perform the manœuvre is by a few preliminary experiments on oneself. There is a certain amount of pain, but it is within the limit that can be borne without flinching, and an anæsthetic is not necessary. Cocaine may be applied to diminish the pain, either by utilising the process of electrical osmosis (§ 153) or by smearing on the skin a small quantity of the following ointment:—

℞ Cocaine hydrochlorat. ... ... ʒ i.
Menthol
Chloral hydrat. ... ... āā ʒ ij.
Lanoline ... ... ℥ ss.
M. ft. ung.

This prescription is recommended in *Dr. Hayes'* very useful little book.* Sometimes the hair is grasped by an epilation forceps held in the left hand while the needle electrode is being introduced, and the electrolysis is allowed to go on until the hair comes out, but on the whole the method first described is perhaps the best. *Dr. Hayes* who has given considerable attention to the process of epilation prefers to use a very fine needle which is blunted or even slightly bulbous at the point, because such a needle is less likely to penetrate too deeply and so pass away from the hair follicle. There is no object in using a platinum or iridium needle. Steel answers every purpose, and is stronger. The current may be closed after the needle has been placed in position by means of a key on its handle (fig. 83), less pain is felt when this is done.

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* "Electricity in Facial Blemishes," *P. S. Hayes, M.D.*, Chicago, 1889.

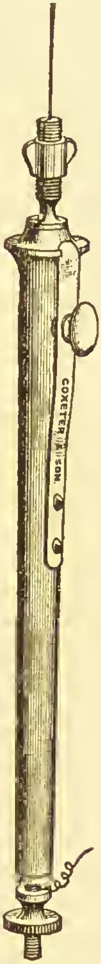

FIG. 83.—Needle electrode for epilation.

A good deal of practice is required to perform this little operation skilfully, no force must be used in removing a hair, if force is used the hair will come out before the follicle is destroyed, leaving its root behind, and a new hair will grow up from it. When many hairs are to be removed they should be done at successive sittings. Ladies as a rule become restless from the pain of the operation after ten or twelve hairs have been taken out, and cannot then keep quite still. A tiny eschar with a small zone of redness is left round the follicle. Several hairs in close proximity should not be attacked at the same sitting, for fear lest the nutrition of the skin should be so much interfered with as to lead to a small ulcer and consequent scar, but the hairs should be removed sporadically, until at the last sitting the few remaining ones can be gleaned off and the place left smooth and bare. If the patch of hairs is small the sittings must be less frequent; when there is plenty of room to attack a fresh part each time the sittings may be repeated daily, care being always taken not to injure the skin at any one point too much.

It is as well to caution patients that there will be a small percentage of returning hairs, but that these can be dealt with a second time if any should so return.

264. **Trichiasis.**—The removal of eyelashes for trichiasis is most perfectly accomplished by electrolysis, and this is by far the best method of treatment for this condition. We have seen most remarkable improvement produced in this way. The patient was a man of middle age. At the commencement of the treatment both his corneæ were hazy from the presence of pannus as a result of the continued irritation by the turned in eyelashes; the removal of the eyelashes was persevered with until every one had been removed; by that time the corneæ had recovered perfect transparency. The patient was most enthusiastic at the great improvement, especially as epilation with forceps had previously been tried without benefit.

265. **Hairy moles.**—The best treatment for hairy moles is epilation; when the hairs have been removed very little will be seen of the mole, but if it should be pigmented, the electrodes suggested by *Mr. R. W.*

Parker and figured by *Dr. Steavenson*,* can be used to produce superficial destruction of its surface. These electrodes (fig. 84) consist of flattened metal plates covered with platinum foil, of various shapes and sizes, and with handles, they are attached to the negative pole of the battery and held to the moistened surface of the mole, whilst a current of fifty or sixty milliampères is passed through them; electrolysis is set up, and a slippery and alkaline material is produced, and the surface is gradually destroyed. The plates are inclined to slip during the operation, this must be guarded against, or sound skin may be destroyed as well as the mole. Chloroform must be given as the process is very painful. If epilation has not first been carried out, this process may be continued until the skin is destroyed down to the depth of the roots of the hairs, which can then be wiped away, but a scar follows this operation, and may be almost as disfiguring a blemish as the mole had been. Therefore, epilation should first be performed, and then the plates may be cautiously used if necessary, for sometimes a slight superficial treatment will remove pigmentation without destroying the whole depth of the cuticle. Compare the method of

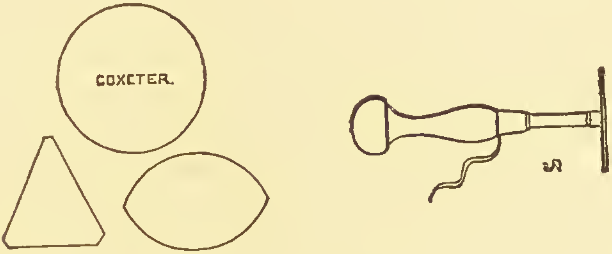

Fig. 84.—Plate electrodes.

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* *Steavenson*, "Electrolysis in Surgery." *Churchill*, 1890.

removing freckles by the application of weak mercuric chloride solution.*

Warts may be destroyed by electrolysis if this method is wished for, other surgical measures, however, are as good as or better than electrical treatment for this particular purpose.

266. **Nævus.**—Electrolysis is a very convenient way of destroying nævi, and in some respects it is superior to all the other methods, but, to secure first rate results, a certain amount of practice is necessary. The chief art in treating a nævus lies in the careful regulation of the current used. It is easy to electrolyse a nævus in such a way as to destroy it and cause it to slough away completely, but this leaves a scar, and the results are no better than can be obtained by ligature or caustics. The object to be aimed at in the electrolysis of nævi is to carry the destructive action just so far as to coagulate the blood and break up the blood-vessels without producing a general necrosis and sloughing of the whole. When the nævus is entirely subcutaneous, it is most important to save the skin, for then the nævus is destroyed without any scar except at the minute points where the needles were introduced. When the nævoid tissue is quite superficial and involves the actual thickness of the skin, it is extremely difficult to destroy it without sloughing. The direction in which more investigation is necessary is towards learning what current or rather what density of current may be used without producing too complete destruction of the parts around the needles.

The usual plan of treatment is as follows:—Needles attached to the poles of a battery are introduced into the nævus, one of *Gaiffe's* galvanometers (fig. 64) is included in the circuit, the current is then very gradually raised from zero up to 40, 60 or 100 milliampères. Care must be taken that the needles of opposite poles do not touch one another. If they remain in contact all the time, the current simply runs to waste through the metallic circuit so produced, and the nævus tissue is unaffected ; if they come into momentary contacts, the patient receives a shock each time they touch and separate. For children who are under an anæsthetic, these shocks are very undesirable, and with the currents used they may produce symptoms of collapse, especially if the nævus be on the head or face. Soon after the commencement of the operation the tissues round the needles begin to change colour ; round the positive needles there is hardening and pallor, and round the negative needles frothing is produced with the evolution of hydrogen gas. When platinum needles are employed, gas is also given off at the positive pole, one volume of oxygen being liberated there for two volumes of hydrogen at the other pole. The positive needles become firmly adherent to the tissue in which they are imbedded, the negative needles become very loose and are apt to slip out, but they must not be allowed to do so, for the current must not be suddenly interrupted for reasons already mentioned. Soon the tissues immediately round the needles become livid or blackened, this change shows itself first at the negative pole, and their position must then be changed by taking them out and re-inserting them one at a time in other parts of the nævus, until the whole of it has been treated.

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* *Hebra* on "Diseases of the Skin," New Sydenham Society, vol. lxi.

An erythematous blush develops round the nævus during the process of electrolysis. Ten minutes is a suitable length of time, but this should be varied with the size of the nævus. If the nævus is very extensive it must be dealt with in detail, part being attacked at each sitting until the whole has been destroyed.

The needles are to be carefully withdrawn after the current has been very gradually lowered to zero, they must on no account be plucked out while the current is still running. The negative needles are easily withdrawn, but the positive may be adherent and should be twisted out gently. A little bleeding may follow from one or two of the punctures, but it is rarely of any importance. It has been recommended to re-introduce any needle which has left a bleeding point, and pass along it a reversed current for a few moments after the others have all been removed (except one of the opposite pole for completing the circuit). However, a little piece of absorbent wool and a turn or two of bandage usually suffice to stop any bleeding. The after-treatment is simple. The part may be left to form a dry scab, or a little boracic ointment can be applied to it for the first few days. After that if any suppuration or local sloughing should develop, an occasional poultice at night, with some boracic ointment by day, will be a suitable treatment. Many of the smaller nævi dry up and need no application at all. It is almost impossible to avoid destruction of the skin and scarring when the nævus is cutaneous, but the scars produced are much smaller than might be expected, and are perhaps less extensive than after other surgical methods of treatment. Sometimes the positive needles only are introduced into the nævus, the circuit being completed through the patient's body by using a large pad for an indifferent electrode. In this case the resistance is much higher, and therefore a larger number of cells is required. There is a greater risk of shock or faintness, especially with nævi of the head and face, but with care the operation can be carried out successfully. The advantages of this method are that the positive needles produce less severe destruction, and so there is less chance of a slough being formed. Also there is no risk of short circuiting and shocks from contacts of needles of opposite pole in the nævus itself. Moreover, the density of the current is more uniform, and therefore the destructive process is also more uniform.

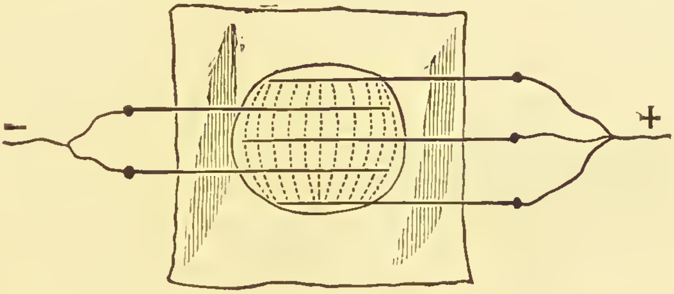

FIG. 85.—Electrolysis of nævus. Proper position of needles.

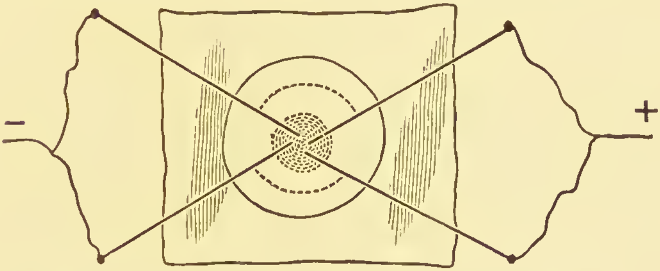

FIG. 86.—Electrolysis of nævus. Improper position of needles.

The rate of destruction depends upon the density (§§ 68, 137) of current at any part, if needles of both poles are introduced irregularly, it is very likely that the current may be concentrated round the points where they are nearest together, and be very feeble in the more remote parts. The diagrams (fig. 85 and 86) represent the conditions under two different arrangements of needles, in the first the needles are placed in such a way as to be equidistant, and the density of current is therefore uniformly diffused. In the second, they are all very near together at the points and there the current is of far greater density than at the periphery of the nævus, the effect of such an arrangement would be to produce a slough at the centre, while the periphery would not be destroyed at all. In order to simplify the introduction of the needles in a proper manner, the writer[*] has devised an instrument (fig. 87) consisting of a handle to carry the needles, two, three, four or five can be screwed into it, and they are so arranged as to be alternately positive and negative (see the smaller of the two figures). By this means the needles are kept at equal distances from one another throughout the operation, and they cannot touch accidentally, and they can be moved about simultaneously inside the nævus so as to bring the whole of it into the reach of the current.

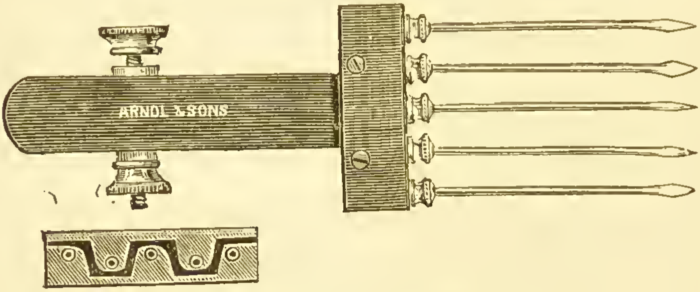

FIG. 87.—Bipolar fork electrode.

It is difficult to formulate a rule for choosing the current to be used, but it is the density of current which is the important point, more so than the actual number of milliampères employed. In the treatment of uterine fibroids by electrolysis the current at both poles is the same, but at the china clay abdominal electrode the density of current per unit of surface is small, by reason of its extended area, and no electrolytic effects are produced there, while the intra-uterine electrode is of much smaller surface, and the density of current is proportionately greater, and very decided electrolytic effects are produced at its surface. For the present we might say that the current density should not exceed thirty milliampères per inch of positive needle if it is desired to avoid sloughing in a nævus. Thus, with four needles introduced for a distance of one inch, two being positive, a current of sixty milliampères would be sufficient; and with twice the number introduced for half that distance the same current would yield the same effects.

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[*] *Dr. Lewis Jones*, "Brit. Med. Journal," Feb. 20th, 1892. An improved instrument for the electroylsis of nævi.

The apparatus required.—Ordinary *Leclanché* cells will do very well for the electrolysis of nævi, and the *Hellesen* dry cell also answers admirably. When cases are to be treated at their own homes, small cells may be used for the sake of their portability, but the current required will naturally tend to exhaust small cells rather fast, so when possible it is better to use larger ones. The dial collector must work very smoothly, the galvanometer (§ 131) must read up to 100 milliampères or more. *Stöhrer's* battery or any other battery may take the place of the *Leclanché* or *Hellesen* cell, but they are not nearly so convenient. Twenty cells are amply sufficient.

The usual arrangement of wires is shown in the figures, it consists of two parts, (1) a main lead (fig. 88) from the pole of the battery terminating in a binding screw, and (2) several secondary leads or branches each carrying a needle, and all attached to the binding screw of the main lead. The needles should be of platinum, and insulated except at the ends, in some the metal must be bare for a distance of half an inch, and in others for an inch, to suit the different sizes of nævus. The whole of the bare part of the needle must be buried

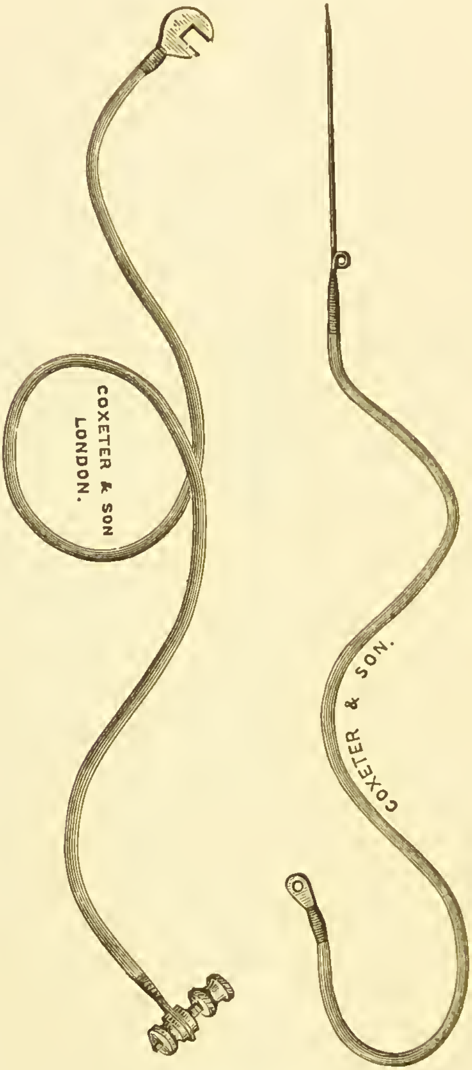

FIG. 88.—Attachment of needles.

in the nævus, in order that an insulated part may be in contact with the skin, this diminishes the size of the marks which will be left at the points of entry, and it is for this reason that needles are required with bare points of varying length. When needles of one pole only are used, the other (indifferent) electrode must be a pad of large size, to diminish as much as possible the density of current at its surface of contact, and also to diminish the resistance.

Care must be taken to prevent the needles from touching the patient's skin by accident, or they will destroy it at the point of contact.

The needles are attached to the ends of the wires in various ways. Soldering is much the best, though the clamp (fig. 89) is convenient. Unions effected by twisting the wire round the needle are bad, for they may break adrift at a critical moment and give rise to shock. With 100 milliampères, such shocks are dangerous to infants under chloroform.

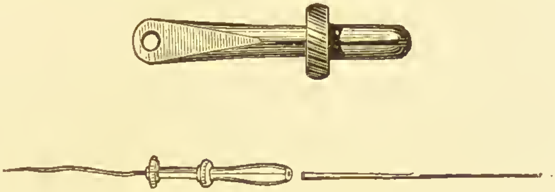

Fig. 89.—Clamp needle holder.

An anæsthetic need not always be given with older patients, but it is far better and more convenient that it should be used, the pain is severe during the passage of the current, but does not seem to persist after the operation is over.

267. **Port wine mark.**—This form of nævus can be attacked by a process similar to that used in epilation,

several needles may be used at once, either separate or fixed in prongs in a handle, the result to be aimed at is a sort of tatooing of the surface, to produce minute points of destructions without confluence of the resulting minute sores. Five milliampères per needle point is a sufficient current for good results. The positive pole is best, but both may be used. The cocaine ointment mentioned above (§ 263) will usually suffice to obviate the necessity for a general anæsthetic. The area affected must be treated in a sporadic manner as advised for the removal of superfluous hair. The result is a distinct improvement in the aspect of the surface.

268. **Aneurysms.**—Electrolysis has been tried for the cure of aneurysms, particularly for those which are not suitable for treatment by ligature or compression. In many of the cases recorded, some temporary increase of hardness has followed the operation, but the cures are but few, and the punctures made in the sac walls have sometimes led to hæmorrhage. The piercing of the wall of the aneurysm by the needles, with the consequent risk of bleeding is the chief defect of the operation; it may be lessened by the use of needles insulated except near their point, so as to limit the electrolytic process to the interior of the aneurysm, and to prevent any action upon its wall.

The method which is generally preferred is to introduce both positive and negative needles into the tumour; the needles attached to the positive pole become corroded if they are made of steel, but this is not an objection, for coagulation is promoted by the salts of iron so produced. *Ciniselli*[*] has collected 23 cases, of these, six recovered, sixteen died, and one case disappeared from observation. Some of those reported as cured had relapses a few months later. See also "Brit. Med. Journal," 1890, vol. i., p. 1276, for a report of successful result after thirteen sittings in a case of aortic aneurysm.

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[*] "Treatment of Thoracic Aneurysms by Electro-puncture," Milan, 1870.

As far as can be made out from the details furnished, the electrolysis of aneurysm requires large currents and long sittings. Twenty, thirty or forty cells have been used, and the application continued for half-an-hour or more. Assuming the internal resistance to have been 100 ohms (it may have been much lower), and putting the electromotive force of the cells used at one volt a piece, then twenty cells would give a current of about 200 milliampères, and forty would give twice as much. This current if continued for half-an-hour, would be sufficient to set free a considerable amount of electrolytic gases, and in some of the cases we read that the tumours became resonant to percussion after the operation. The free acids and alkalies produced by the electrolytic separation of the neutral salts of the blood would probably soon recombine in their passage along the blood stream. The clotting produced in the aneurysm is soft and diffluent.

269. **Stricture of the urethra.**—Modern writers on this subject refer to *Crussel*, 1839, as the first to use electrolysis for the cure of this condition, and to *Mallez* and *Tripier*[*] as the first to practise it systematically. A good deal has been made of the difference between electrolysis of a stricture, and destruction of it by the caustic alkali set free electrolytically at its surface, as though the former process were something essentially different and less injurious than the latter. It has also been claimed that the stricture can be cured without any

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[*] "De la guerison durable des rétrécissements de l'urethre par la galvano-caustique chimique," Paris, 1867.

destructive action upon the mucous membrane which covers it. We are disposed to think that the yielding of a stricture during electrolysis is always due to its actual corrosion by the alkali liberated at the negative pole, and that the mucous membrane, because it is nearest to the electrode, must be the first part to perish. However, those who have devoted considerable attention to this matter, are inclined to believe that the epithelium is not destroyed, although the fibrous tissue beneath it is removed. *Mr. Bruce Clark* in a paper on the subject* says :—" Where I have had an opportunity of treating an orifice stricture it is clearly demonstrated that with such currents as one usually employs, no solution of epithelial continuity takes place," and again: " That absorption does take place can be witnessed when a stricture at or within half an inch of the urethral orifice is submitted to treatment. In these cases the surface of the epithelium is seen to be gradually converted into a glutinous saponaceous-looking material. If this be wiped carefully away, the surface is seen to be red and somewhat congested in appearance, but it is perfectly evident that the epithelium is not entirely removed with such currents as I am in the habit of employing."

In a paper read at the Annual Meeting of the British Medical Association, in 1886, by *Dr. W. E. Steavenson*, the following account of electrolysis of stricture occurs :— " No doubt this procedure will become one of the recognised modes of treatment of stricture in this country, as it has been for many years on the continent and in America. Since our paper was read the plan we advocated has been adopted by several surgeons in London and in different parts of the country. Favourable corroboration of our results has come from St. Peter's Hospital for Stone, from Dublin, and from private sources. It may not be destined to become the most usual mode of treatment, although the most effectual, because of the elaborate apparatus required, the numerous details connected with its application, and the great care and patience required for its successful employment.

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* The Treatment of Stricture of the Urethra by Electrolysis, " The Practitioner," 1886.

"For the treatment of stricture of the urethra, the electrodes we have used are catheter-shaped gum-elastic bougies, ending in a metal nickel-plated piece which is connected by a copper wire, which traverses the whole length of the bougie, with a binding screw on the handle. The bougies were made by *Messrs. Maw, Son and Thompson.* In the electrolysis of strictures, it does not matter of what metal the uninsulated part of the bougie is made, as the electrode during the passage of the current is kept negative, and therefore the metal is not affected, and the bougie is withdrawn as bright as when introduced. In one or two of our earlier cases, so little sensation was produced in the patient during the passage of the current, that it was difficult to believe, in the absence of a galvanometer, that any decomposition was taking place at all. The current was therefore once or twice reversed with the commutator for a second or two, with the result of immediately oxidising the nickel plating on our electrode, which will be seen in some of the instruments I have brought with me. The shock of making and breaking the current soon satisfied us and the patient that some uncommon force was present in his urethra. The other electrode in the shape of a flat plate of tin covered with amadou to retain moisture, is placed upon the patient's back if he is in a recumbent position, or it may be placed on any other indifferent part of the body, such as the inside of the thigh. The metal plate is made positive.

"An ordinary bougie is first passed down to the stricture, and by its means the distance of the stricture from the meatus is ascertained, and a mark made on the bougie. It is then found out what sized bougie will pass the stricture. Say, for instance, it is ascertained that a No. 3 bougie (English) will pass; a No. 5 electrode is then taken and passed down to the stricture, where it is arrested. It can be made certain that the electrode is arrested at the stricture by previously marking it, after measurement and comparison with the bougie first passed. When the electrode is in position against the stricture, it is connected with the negative pole of the battery, and the current closed and then gradually increased without breaks until the maximum strength of current is reached that it is intended to employ, namely, about five or six milliampères. The electrode is kept gently pressed against the stricture in the direction of the ordinary course of the urethra. No force is used, but the current is allowed to do the work. The surgeon has to keep his attention continually applied to the electrode, so as to guide it in the right direction, otherwise a false passage may be dissolved into the side of the urethra. Therefore skill in passing a catheter is a requisition. In the hands of a surgeon who knows his way into the bladder, a false passage is not more likely to be produced than is the case in passing an ordinary catheter. The electrode is to be kept gently pressed against the stricture in the normal direction of the urethra until, from the dissolution of the obstacle in front of it, it passes into the bladder. The current then should immediately be cut off, and the bougie withdrawn. The duration of the operation depends upon the density of the stricture and the strength of the current used.

"Although as a guide I have mentioned that the current should be about six milliampères, the strength really used is regulated by the patient himself. One great object is to avoid giving pain, and by this means a too great destruction of tissue is prevented. We require our patient to be conscious; therefore no anæsthetic is used, or indeed necessary, for the only sensation produced is a slight pricking at the seat of the stricture. If anything amounting to pain should be complained of, the strength of the current has to be diminished. On removing the electrode, there is sometimes found on it some slimy matter like disintegrated tissue; and the patient is often immediately after its withdrawal enabled to pass urine with increased facility and with very little discomfort. After the operation we have left the patient entirely free, without any interference, for usually the space of ten days or a fortnight, and then have tried what sized bougie would pass. If no disintegrated tissue comes out upon the electrode, some sort of slough or eschar is thrown off at a later period—the next day, or a day or two after the operation, during the passage of urine.

"Going back to the example we have already taken, if, after dissolving the stricture, it has been possible to pass a No. 5 electrode into the bladder, after the rest of a fortnight it is usually found that a No. 7 bougie can be passed. Should that be the limit of the increased calibre of the passage, a No. 9 electrode is taken, and the same operation repeated as before described, and so on after the interval of another fortnight, until the stricture is cured. Before the Royal Medical and Chirurgical Society we summed up the results of our investigations as follows: In the treatment of stricture of the urethra by electrolysis, there is usually no bleeding. If hæmorrhage does occur, it is accidental, and usually shows that a too strong current or the wrong pole of the battery has been used. No anæsthetic is required. It is an assistance to the operation that the patient should remain conscious. The pain or discomfort produced is trifling. The patient can in the case of a slight stricture pursue his ordinary occupation during the period of treatment. No antiseptics are required, as the process itself is aseptic. In the majority of cases there is no contraction or return of the stricture.

"Eschars formed by caustic alkalies are said to heal with less contraction than wounds produced in any other way, and electrolysis with the negative pole is a means of applying the destructive action caused by the caustic alkalies to parts difficult of access, and in a way which is impossible by any other method. But beyond this, the current appears to set up an absorptive action around and within the dense cicatricial tissue which forms the stricture, so that it gradually disappears. This we have seen in several ways. After electrolysis has proceeded so that the electrode will pass into the bladder, it is found a fortnight later that a bougie of two sizes larger can be passed. Additional absorption must therefore have taken place in the interval. And again in penile strictures, where we have been able to feel the hard dense tissue of which they are formed, a few days after electrolysis, we have noticed that this hardness has disappeared.

"This progressive improvement after the termination of treatment is very remarkable, and lends some colour to the belief that an actual absorption of fibrous tissue may be determined by the passage of the current. It has also been stated that the cure is more permanent than it is after ordinary dilatation."—For reports of *Mr. Bruce Clarke's* cases, with their subsequent history, see "Practitioner," 1886. "British Medical Journal," 1890, vol. i., p. 942.

In a letter of recent date (1892) *Mr. Bruce Clarke* writes that he still considers the results of electrolysis to be extremely good and permanent in cases of stricture. Of a patient who was treated by him in 1885, he says:—"I saw him a few days ago, and passed a No. 11 with the greatest ease. No instrument has been passed since the operation, except by myself once or twice for purposes of diagnosis."

270. **Stricture of the œsophagus.**—Electrolysis has been recommended for this form of stricture by most writers on medical electricity. We have not been able to find any report of a case.

271. **Stricture of the rectum.**—This can also be treated by means of electrodes shaped like rectal bougies, which are connected to the negative pole of the battery. A bougie is selected of a size rather larger than the stricture, to which it is applied firmly. A current of five or ten milliampères is passed. After a variable time the stricture gives way, and the bougie passes through it. The time of each operation may be from ten minutes to half an hour. The operation is repeated with a larger instrument in ten days or a fortnight. No anæsthetic is required.

272. **Eustachian obstruction.**—In the "Lancet" for Nov. 1888, a paper on electrolysis of the Eustachian tube was published by *Mr. Cumberbatch* and *Dr. W. E. Steavenson.* The authors described their methods as follows:—"The instrument consists of a vulcanite

Eustachian catheter and an electrical bougie (fig. 90), the bougie is made of a fine flexible copper cord about seven or eight inches long, insulated by vulcanite to within an eighth of an inch of its end. The ends are soldered into a nickel plated cap. The bougie is small enough to pass along the catheter, and exceeds it in length by about an inch. The handle end of the bougie is provided with a binding screw, to which the insulated copper wire is also attached, for the purpose of connecting a rheophore from the battery. On this end of the bougie an inch is marked off divided into eighths. Each eighth of the inch passes into the catheter as one eighth protrudes at the other end. It is therefore possible to tell, when the catheter is in the orifice of the Eustachian tube, how much of the bougie is in the canal. On the cathether there is a metal ring, or some other mark, to indicate the direction of its end when it is being inserted.

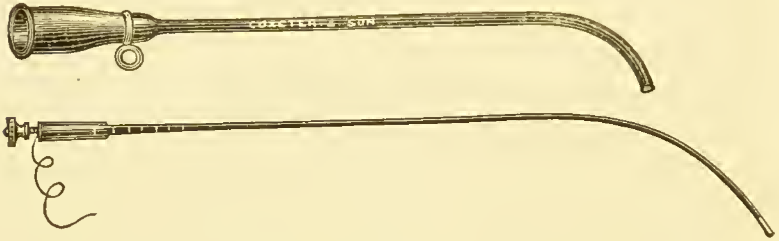

Fig. 90.—Eustachian catheter electrode.

Electrolysis of the Eustachian tube is performed in much the same way as the electrolysis of the other mucous passages. A pad connected with the positive pole of a battery is moistened and placed at the back of the patient's neck. The Eustachian catheter is then passed along the nostril and guided into the tube; the bougie, already attached to the negative pole of the battery, is passed along the catheter and Eustachian canal as far as it will go, until it meets an obstruction. The circuit is then closed. A galvanometer should be included in the circuit, and the current gradually increased up to four milliampères. A frizzling noise will be heard by the patient in his head, and the operator, by approaching his ear to the catheter, may hear the crackling produced by the breaking of minute bubbles of gas. The electrolysis is kept up for four minutes, and usually before the expiration of that time, if it is possible that the obstruction can be removed, it will be found that the bougie can be pushed on for a small distance, sometimes for its full length. Generally on the first occasion the Eustachian tube is rather sensitive, but it seems to acquire toleration for the process, and at no time is so much discomfort experienced as might be expected. The operation has now been performed a large number of times without any unpleasant experiences, nor has the treatment caused any pain, either at the time or afterwards.

In favourable cases there is an immediate improvement in the hearing, as tested by the greater distance at which a watch can be heard after the passage of the instrument; the distance at which it is heard may be doubled. In other cases the results are not so good, partly from the difficulty of reaching the Eustachian tube, and partly no doubt from other causes."—

273. **Lachrymal obstruction.**—In a paper by *Mr. Jessop* and *Dr. Steavenson** an account is given of ten cases of lachrymal obstruction treated by electrolysis. The advantage of the method is again due to the ease with which the action can be confined to the exact parts needing treatment. The instrument used by

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* "Brit. Med. Journal," December, 1887.

them is a curved platinum probe. The operation is very simple; the current required is small, two to four milliampères being sufficient, and the duration is thirty seconds. No anæsthetic is needed; the probe must always be negative, the positive pole being the usual pad indifferent electrode. Two or three sittings suffice to produce cure of the obstruction. The cases related are confined to those in which the obstruction was at the puncture or in the canaliculus, and not in the sac itself. The operation is simpler than the slitting up of the canaliculus, and the improvement is permanent.

274. **Electrolysis for uterine fibroids.**—Since the publication by *Dr. Georges Apostoli* of his method of treating fibro-myoma, an immense amount of literature has been produced on the subject.* Much has been said both for and against *Apostoli's* treatment, and the enthusiasm which was at first shown in its favour by many writers, has to a large extent been followed by a reaction against it. There is no doubt, however, that electrolysis must hold an important place in the treatment of fibroids, because it offers an alternative to the very serious operation of abdominal section, and in many cases it affords great relief to the symptoms of the patient, even if it does not effect a radical cure of the disease. We propose here to give a short abstract of *Dr. Carlet's*† original paper, produced under the immediate direction of *Dr. Apostoli.*

The early attempts at treating fibroids by electrolysis were done by *Cutter*, 1871; *Routh* and *Althaus*, 1873; *Brachet*, 1875; *Semeleder*, 1876; *Everett*, 1878; *Aimé*

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* See the Medical Journals, 1888, 1889, and publications by *Drs. Steavenson*, *Bartholow*, *Bigelow*, *Keith*, *Massey*, *Engelmann* and many others.

† "La traitement électrique des tumeurs fibreuses de l'uterus," *Dr. Lucien Carlet*, Paris, 1884.

Martin, 1879; *Gallard*, 1881. In 1882 *Apostoli* communicated a paper to the Académie de Médecine, in which he described his method of procedure. He recommended an internal positive electrode of platinum, and an abdominal electrode (negative) of moist china clay of large surface, and a continuous current of sixty to seventy milliampères, for from five to fifteen minutes. In certain cases when the internal electrode could not be passed into the cavity of the uterus, he thrust it through the cervix into the tissue of the uterus instead. Sittings once or twice a week. The action of the current was to produce destruction of the uterine mucous membrane. The results were to reduce the size of the uterus, and to decrease the hæmorrhage. The destruction of the mucous membrane is followed by a healthy process of repair, by a process of involution, and by a cicatrisation which checks the metrorrhagia.

Drs. Apostoli and *Carlet* arrange their account of the operation as follows :—

1. *The seat of the operation.*—It must be intra-uterine, and the internal electrode must occupy the whole depth of the uterine cavity. To puncture the uterus from the abdomen is dangerous, for suppuration and peritonitis are likely to follow, adhesions are likely to be formed, and the uterine mucous membrane is not touched.

2. *The nature of the operation.*—The positive pole is indicated for the internal electrode when hæmorrhage is the chief symptom, the negative pole may be used when the fibroids are large, hard and subperitoneal, and when there is not much hæmorrhage, for if anything it increases the tendency to bleeding.

The current must be quite uniform, and must be raised and lowered very gradually, sudden interruptions with the large currents used are sufficient to give dangerous shocks.

3. *The strength of current.*—The maximum strength which the patient can bear is to be employed; when the uterus is large, a greater strength is needed to produce the same density of current (see § 137). Cauterization is easily obtained in an uterus of little length owing to the smaller surface for distribution of the current, but a much greater current is needed with a lengthened uterus, owing to its greater area. One hundred milliampères is the mean strength used by *Apostoli* since 1883 (date of *Dr. Carlet's* paper, 1884), and this is generally well borne by the uterus. In hysterical patients the current is not well borne, or rather a fit may threaten, unless the current is very cautiously increased. The operation must not be undertaken during acute perimetritis (or any other febrile condition).

4. *The duration of the operation.*—The mean duration should be from five to ten minutes, according to the gravity of the case and the tolerance of the patient. When patients have to return home immediately afterwards, five minutes suffices in most cases. A strong current for a shorter time is better than a lesser current for a longer time.

5. *The number of sittings.*—An absolute cure with complete restoration to health (*ad integrum*), is and will ever be, beyond our medical resources. Our hope is that we may reduce the size of the tumour by one-half or one-third, and remove the symptoms. Whether the tumours persist or not, the operator should persevere until the symptoms are relieved, and he ought not to be satisfied till this goal is reached. "He should depend on the general condition and statements of the patient, and not on what digital exploration reveals."

Twenty or thirty sittings is the mean number, but many patients declare themselves cured after five to ten sittings. "If after great amelioration the patient desires to gain all she can from the treatment, it may be resumed, but the progress will be much more slow than at the commencement."

6. *Choice of time.*—When pain and losses are not very great and other symptoms are not acute, choose the inter-menstrual period, but on the other hand, with serious symptoms making life miserable or endangering it, begin at once, even during severe bleeding.

The interval between sittings should be long enough for all pain or discharge produced by the previous ones to have ceased. The operation may be performed once a week, or even twice a week if the patient is able to keep her bed or to remain very quiet.

7. *Technical details.*—Before commencing, explain to the patient what is going to be done, make sure that the battery is in good order, and that all wires and connections are sound, disinfect the internal electrode, adapt the abdominal electrode of potter's clay carefully to the surface of the skin, first covering any little abrasion or acne spot, however small, with a piece of oiled silk or guttapercha tissue. The patient must remove her stays and loosen all her skirts, and the abdomen must be quite bare. She must recline on her back on a couch or across the bed, the vagina must be thoroughly syringed out; finally she must be assured that the operation will not be very painful, and that at the slightest sign from her the strength of current will be reduced, on the other hand she must be encouraged not to complain unnecessarily; place the clay electrode on the abdomen, see that its margins do not touch the groins or pubes, attach the battery wire, then introduce the internal electrode with great care and gentleness. (This

is the most difficult part of the operation, and it may be better to do it before applying the abdominal electrode). Make sure that it has passed to the full length of the uterus, examine to see that the vagina and vulva are perfectly shielded from metallic contacts, and encourage the patient to press with her palms upon the clay electrode, so as to keep it well applied. Do not commence the current till all pain from the introduction of the electrode has passed off. After the operation tell the woman that she will have pains for a few hours, and a slightly tinged discharge for a day or two. She must rest for two hours before going home, and must then lie down. Walking exercise is bad. Conjugal relations must be absolutely forbidden.

Weak injections of Condy's fluid or carbolic lotion should be used once daily.

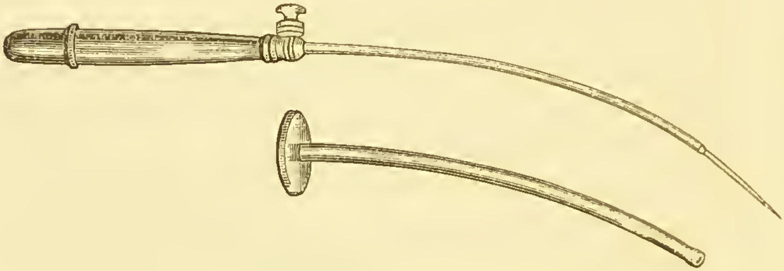

FIG. 91.—Apostoli's uterine electrode and sheath.

The intra-uterine electrode has the shape of a sound, insulated except at its extremity, this part must be of platinum, and its length should be capable of adjustment to suit the length of the uterus. The insulation should reach sufficiently far to protect the cervix uteri as well as the vagina. Care must be taken that no bare metal touches the vulva, or the skin of the thighs, or a painful sore place will be produced.

Dr. Apostoli's sound (fig. 91) is fitted with a sliding vulcanite sheath; platinum pieces, either sharp or blunt, are screwed into the end of the shaft, and are chosen of a length to suit that of the uterine cavity. Subsequently *Steavenson* modified and improved the original pattern by making an electrode shaped like a hard rubber catheter with a platinum tip (fig. 92). The advantage of this shape is that the instrument is more flexible and more easily introduced into the uterus, and the insulation part is not thicker than the rest, therefore it can enter more easily into the cervix so as to protect that part. If this form of electrode be used it will be necessary to have a set with platinum ends of different lengths, whereas *Apostoli's* sound can be altered to suit each case by means of changing the platinum points.

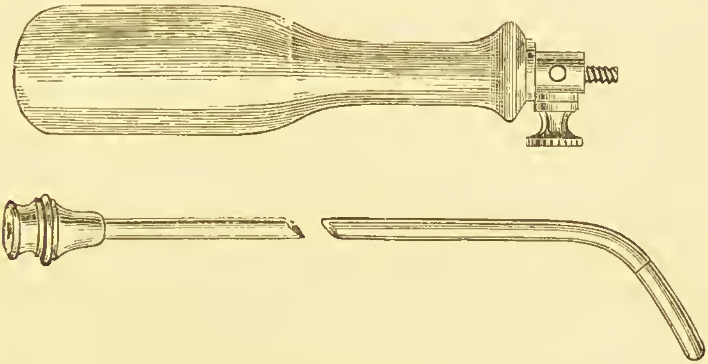

Fig. 92.—Steavensons electrode for fibro-myoma.

The electrodes with sharp points are made for puncturing the uterus when the cervical canal cannot be reached. Puncture, however, is now very rarely practised.

An ordinary uterine sound made with a platinum point and fitted with a binding screw answers the purpose very well, the stem can be insulated by a thin soft rubber tube slipped over it, leaving bare the appropriate length at the end, this soft tube will enter the cervical canal quite well, the advantage is that such an instrument can be kept absolutely clean, a new piece of rubber being slipped on for each operation and a little vaseline smeared over to protect against any possible escape of current through minute holes in the rubber.

The abdominal electrode is prepared by making up a putty like mass with the potter's clay and water, it is then spread out evenly on a piece of muslin in a layer half an inch thick. A metal plate with binding screw is embedded in its upper surface, and the muslin is folded over to enclose a round cake of the clay. It should measure about nine or ten inches in diameter.

The preparation of this electrode is rather troublesome, and it is heavy and rather messy for the patient, but it adapts itself well to the surface of the abdomen and gives good results. Substitutes for it have been devised, such as large flat bags of bladder or dialysing parchment containing warm water. These will also adapt themselves very closely. Metal plates covered with moistened flannel, or carbon in small lumps covered with flannel to form a cushion have also been tried.

A firm cake of gelatine also conducts very well, and is easily prepared in a dinner plate. It is rather sticky and unpleasant, however, as it has a tendency to melt at the temperature of the body. The addition of one or two per cent. of alum will prevent this, and improve the pad, which is to be enclosed in muslin, and used exactly as the clay electrode. It is then much more cleanly and agreeable than the potter's clay.

In a communication on the use of electricity in gynæcology* *Drs. Aust-Lawrence* and *Newnham*, writing after its use in one hundred cases arrive at the following conclusions. In *Myoma* the results have been as follows :—" There has not been a very great reduction in the size of the tumours, but rapidly growing tumours have been checked in their growth in all instances except one. The bleeding has been lessened in a very marked manner by the intra-uterine use of the positive pole. The pain also has been lessened and in some cases removed entirely. The general health has been much improved, the feeling of weight has been relieved to a great extent, and this out of all proportion to the diminution in the size of the tumour."

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* "British Medical Journal," November, 1891.

They do not regard electricity as a means of cure or even of relief in all cases of myoma uteri; but consider it a very valuable addition to the means of treating a very troublesome set of cases.

They also mention a patient who continued to have profuse uterine hæmorrhage from a fibroid after removal of both appendages, the hæmorrhage was very much lessened by subsequent electrical treatment.

275. **Other uterine disorders.**—*Subinvolution.* Electrolysis has also been used by the same writers for subinvolution. The intra-uterine application of the positive pole with a current of fifty milliampères given once a week for three or four times has a very good effect, the uterus very rapidly undergoing involution, but they are of opinion that when endometritis is present, other intra-uterine medication gives better results.

Stenosis of the cervix can be removed by electrolysis very much in the same way as in the treatment of stricture. Five or ten milliampères for a few minutes usually suffice to enlarge the canal of the cervix. Several electrodes of different sizes may be required, the gain in calibre is said to be permanent.

Dysmenorrhœa and Menorrhagia.—The caustic action of the negative pole has been tried for membranous dysmenorrhœa, the method is exactly the same as that used for fibroids, and menorrhagia apart from fibroids has been similarly treated by the positive pole.

276. **Extra-uterine fœtation.**—Attempts have been made to arrest the progress of extra-uterine fœtation by electrical treatment, and successful cases have been reported after galvanism and after faradism, most of them by American medical men. At the Meeting of the British Medical Association at Brighton, in 1886, *Dr. Aveling* and *Dr. Petch* both made communications on the subject, each reporting one successful case, the former treated his patient, whose pregnancy had lasted three months, by faradic currents, which do not seem to have been at all powerful. One pole was placed on the abdominal surface and the other in the vagina so that the tumour was included between them; after three sittings the tumour began to diminish and the patient made a good recovery. *Dr. Petch's* patient had been pregnant for about six months, and the fœtal heart sounds were audible. Two needles were introduced through the abdominal wall, one at either end of the tumour, they were insulated except for three quarters of an inch at their points, and a current from thirty Leclanché cells was passed* for one hour, the mother was not anæsthetised, and felt only slight pain, the heart sounds were not affected at the time, but four days later they had ceased, the patient made a good recovery and had continued well for two or three years since the operation. In the discussion which followed the reading of these papers several speakers related cases of a similar kind which had occurred to themselves, and the generally

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* Probably about 250 miliampères.

expressed opinion was that electrical treatment might be useful when extra-uterine pregnancy could be diagnosed before the end of the third or fourth month, and before rupture of the tube had taken place; when the pregnancy was further advanced, electricity was not so valuable, because even if the fœtus could be destroyed by its means, there was still considerable risk to the mother of septic poisoning from the retention of the dead fœtus, and it was not likely to undergo absorption, although in *Dr. Petch's* case the tumour, a fœtus at six months, had been reabsorbed without accident. On these grounds *Mr. Lawson Tait* emphatically condemned the use of electricity, and because it was extremely difficult to diagnose the tubal pregnancy before rupture, he considered that abdominal section was far preferable.

In the St. Bartholomew's Hospital Reports, vol. xix., 1883, *Dr. Matthews Duncan* and *Dr. Mason* have published a paper on extra-uterine fœtation, with an account of one case in which electrolysis had been tried; the pregnancy had lasted five months and the fœtal heart was audible. Electrolysis was practised on two occasions with a fortnight's interval. The current of forty cells was employed for six minutes, on the first occasion the poles were in the vagina and on the abdomen respectively; on the second occasion two needles connected with the negative pole were thrust into the tumour while the positive was applied to the abdominal surface as before.

The fœtal heart was not arrested on either occasion. Other means of destroying the fœtus were then employed, and the patient died of peritonitis a week after the second sitting; post-mortem the fœtus was found very considerably macerated, this was considered to have been due to the electrical treatment.

Dr. Percy Boulton[*] has published a case of early (six or eight weeks) extra-uterine fœtation, where electrolysis proved fatal from peritonitis, but there was no post-mortem examination to show what changes had been set up in the tumour. The case shows that electrolysis, even in the early months, is not free from danger.

Dr. Lawson Tait and other speakers at the Brighton Meeting pointed out that very often tubal pregnancy may undergo spontaneous cure. It is very likely that some of those said to have been cured by faradic shocks were really cases of this kind, because it is difficult to see how a moderate faradic current, diffused through the large sectional area of the abdomen, could exert any effect at all upon the tissues of a young fœtus, though it might possibly produce some mechanical compression by setting up tonic contraction of the muscle fibres in the Fallopian tube round it. To slay even a small animal it is necessary to have very powerful faradic currents, carefully concentrated upon a vital part. A fœtus lying in the midst of the conducting tissues of the abdomen could only receive a small fraction of the comparatively small total current yielded by a medical coil.

277. **Cancer.**—The destruction of cancerous tumours by electrolysis has been proposed.

Although it is not likely that electrolytic treatment will do more than produce sloughing of parts of a cancer, yet it is sometimes useful, when nothing else can be done, because the pain of the cancer is often much diminished after electrolysis, as has been observed by *Althaus*. Cures of cancer by electrolysis will be found reported in many of the books on electrical treatment, but a close study will usually reveal some weak point in the history of the cases related. (See also, § 253).

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[*] "Brit. Med. Journal," April, 1887.

CHAPTER XVI.

CAUTERY AND LIGHTING INSTRUMENTS.

The galvano-cautery. Batteries for cautery purposes. Accumulators. Wires and leads. Lamps. Batteries for lamps. Rheostats. The cystoscope. The panelectroscope. The use of electric light mains. The electromagnet.

278. **The galvanic cautery.**—The forms of galvano-cautery in common use are almost innumerable, but their plan of construction depends upon one general principle. The small cauteries used for operations on the ear, eye, throat or nose, consist of small loops of platinum wire mounted on straight or curved copper leads, which are insulated from each other, and then bound together to form a convenient stem (fig. 93). These fit into a handle provided with a key for easily opening or closing the circuit. The platinum loops, owing to their high resistance, become heated by the passage of a current. Many of these handles have conductors barely thick enough to carry the currents required to heat the platinum loop to redness, and although much ingenuity has been expended in designing convenient contacts for

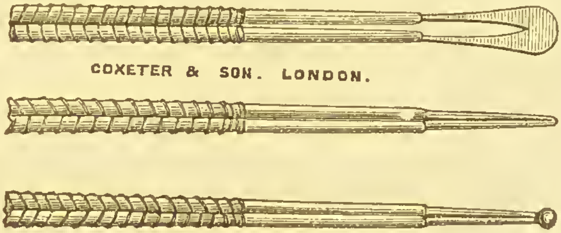
COXETER & SON. LONDON.

FIG. 93.—Galvano-cauteries.

closing and opening the circuit while in use, these are sometimes so badly designed as to add much to the difficulties of the operation. The figure (fig. 94) shows the usual form of handle, known as *Schech's*.

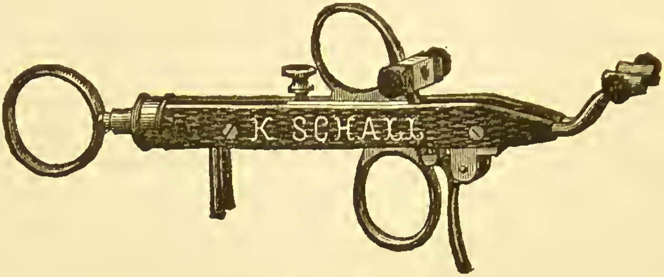

FIG. 94.—Schech's handle.

The shorter handles are more convenient than the large size, which is more expensive, and too unwieldly for delicate manipulations.

If the cautery mounts are too slender, they will become heated. They are insulated by a thick waxed thread twisted round them in racking turns, which keeps them from touching, although binding them together, and forms a sufficient means of insulation, except when they become overheated.

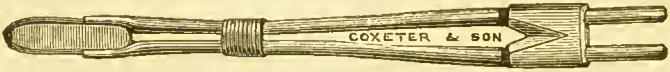

FIG. 95.—Cautery for larger incandescent surface.

Besides the simple platinum loops, cutting instruments of various shapes are made by hammering the platinum flat or by bending it in various ways. Where a larger incandescent surface is required, a loop or spiral of platinum supported in grooves on a porcelain mount is made, the porcelain then becomes heated to redness as well as the platinum (see fig. 95). Different thicknesses of platinum wire are used, and accordingly the current required varies greatly in different cauteries (see below).

Sometimes a long loop of wire is used as an ecraseur, being adapted cold to the part to be removed, and then heated, and a screw can be mounted on the handle figured above for gradually drawing up the wire loop (fig. 96). It is as well here to mention that the temperature of a cautery must never be allowed to rise above dull redness. At a white heat the cauterising action is so rapid that searing of the surface does not take place, and hæmorrhage may follow as profusely as after division of the tissues by a knife. A large number of modified forms of cautery and mount will be found in the instrument makers' catalogues. The resistance of the cauteries just described may vary from ·025 to ·04 ohm.

The current required varies between eight or ten ampères for the smallest, to upwards of twenty for the larger ones.

Still larger currents are required for a few cauteries, which have been constructed for special purposes.

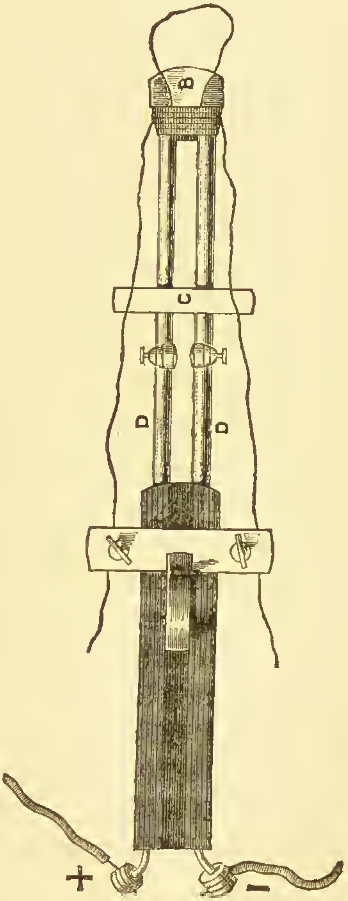

FIG. 96.—Ecraseur.

In the prostatic cautery of *Prof. Bottini*[*] the part to be heated consists of two strips of stout sheet platinum, each 20 mm. × 8 mm., which lie side by side in the concavity, near the beak of an instrument, which is shaped like a vesical sound. The current passes along one strip and returns by the other. The large mass of the platinum makes the resistance of the part to be heated remarkably low, about ·0005 ohm, and consequently an immense current, amounting to fifty ampères, is required to raise it to a red heat. Such a current as this taxes any portable battery to the utmost. This instrument is made for the radical cure of the symptoms caused by enlarged prostate, and its use has been advocated in this country by *Mr. Bruce Clarke*,[†] who has employed it successfully on several occasions.

The current passes through the instrument to reach the platinum strips, the metal tube itself forming one conductor, with a small insulated return-wire down its centre, the rest of the space inside the tube being used as a channel through which water is circulated to keep the instrument cool. The return wire is barely able to carry the large current, and offers considerable resistance, this increases the difficulty of heating the platinum.

279. **Cautery batteries.**—The batteries of small cells which are used in medical treatment are arranged for high electromotive forces with the minimum of weight, and their internal resistance is of little importance. For cautery purposes the conditions are quite different, and the small medical cells are therefore unsuitable. Large bichromate cells have been much used for cautery purposes, but they are very

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[*] "Brit. Med. Journal," 1891, vol. i., p. 1121. Description and figure.

[†] Medico-Chirurgical Society, Jan. 1892.

inconvenient, although they may be made to yield a large current for a brief period. They are heavy and bulky, the attachments of the plates are numerous and likely to get out of order. They require perpetual attention, and they are excited by a very corrosive liquid which is liable to splash over and damage whatever it touches, finally from their tendency to rapid polarisation they are apt to fail suddenly in use.

280. **Accumulators.**—By far the most convenient form of battery for cautery work is an accumulator, they do not polarise and therefore they give a steady current, their internal resistance is very small, their capacity (§ 99) is large, and they will keep in good order for three months without attention. With proper care in use (§ 113) they are perfectly trustworthy. They are heavy, but not more so than any other cautery battery. The *Electrical Power Storage Company* prepares small two cell accumulators for medical purposes, weighing from thirty to forty pounds, with three or five plates per cell. The smaller size will heat cauteries requiring eight to ten ampères fairly well, though it is rather a strain upon them, the larger size with five plates is therefore more economical in use. Still for the brief periods during which the cautery is required the three plate cells will suffice, but if much heavy work is required to be done the larger sizes are the best. At present there is a tendency to return to the original *Planté* type of secondary cell (§ 113), as it has the advantage over pasted plates that it is not damaged by a high rate of discharge, and they will probably be superior for surgical uses. As at present made, they are rather heavier than the E. P. S. cells.

The importance of batteries with a low internal resistance will be seen from the next paragraph. The steady current which can be obtained from any given electromotive force depends primarily upon the resistance of the circuit (§ 56, Ohm's law), and this resistance in the case of a cautery is divisible into three parts : *(a)* battery resistance, *(b)* resistance of leads, *(c)* resistance of the instrument. All of these must be kept down as low as possible.

281. **Leads or conductors.**—By referring to § 121 a table of the sizes of wire suitable for carrying different currents will be found. It will be seen from that table that many of the leads supplied by instrument makers are too slender to carry currents of ten to twenty ampères. If the leads are too small to carry the current easily, more electromotive force must be provided, and a greater weight of battery has consequently to be carried, while in addition the conductors are likely to become dangerously hot, and energy is uselessly expended.

It may be useful to give an example here of the calculations to be made in arranging the apparatus for heating a cautery. Let us suppose that a cautery having a resistance of ·04 ohm and requiring a current of 20 ampères is to be heated. The battery power available consists of two accumulator cells in series, each with an electromotive force of two volts, the internal resistance of each cell being ·01 ohm.

To obtain a current of twenty ampères from four volts the total resistance in circuit may amount to ·2 ohm. If proper leads are used (see table, § 121), their resistance will be ·0014 ohm per metre. We will suppose each wire to be ·5 metres in length, their total resistance will then be ·0042 ohm. The necessary resistances in circuit in this case (resistance of battery, of leads, and of cautery) therefore amount to ·02 + ·0042 + ·04 =

·0642, or say ·065 ohm. This leaves a margin for faulty contacts and for rheostat of ·135 ohm, and the cautery would be adequately and easily heated. For the kind of rheostat used with cautery see § 127.

But now suppose the leads are of a size having a resistance of ·04 ohm per metre. This will give a total resistance in circuit of ·02 + ·12 + ·04 = ·18 ohm, leaving a bare margin of ·02 ohm for faulty contacts. This would certainly be insufficient, as there are several points of contact and a small degree of oxidation or tarnishing at any one of them would be sufficient to prevent the cautery from heating, add to which there would in all probability be a considerable amount of heating in the leads, which would certainly increase their resistance, and might destroy their insulation.

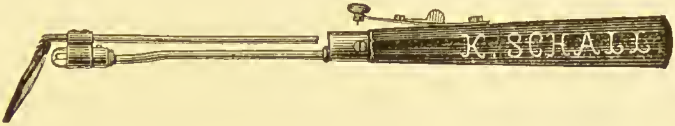

FIG. 97.—Laryngoscope, with electric lamp.

These examples show the importance of using stout conducting wires with plenty of copper in them, and of keeping all contacts and binding screws scrupulously clean and bright. A rheostat must always be included in the circuit when a cautery is to be heated, if this precaution is neglected, there will be much trouble from over-heating and fusing of the platinum loops.

282. **Surgical lamps.** — The small incandescent lamps used for surgical purposes have already been considered in § 122. These little lamps have been adapted to laryngoscopes, ophthalmoscopes, endoscopes and other instruments (figs. 97, 98). They are not used very universally, because in many cases the maintenance

of the battery is troublesome, and because other sources of illumination are sufficient.

These small lamps vary a good deal in their resistance (10-15 ohms), and therefore the electromotive force required to light them properly varies also. If the filament is slender, or if it is long, their resistance is high, if it is short or thick, their resistance is less high. A long slender filament may require eight or ten volts to light it properly, while a shorter one will glow with six volts. The tendency at present is to increase the length and resistance of the filament, for the sake of the better light to be obtained in this way, and although a larger number of cells must be provided to overcome the higher resistance, the current consumed is less, and the cells last for a longer time. The rate of consumption of energy by a ten volt lamp which glows properly with ·4 of an ampère is four Watts (§ 122), while that consumed by a six volt lamp using ·7 of an ampère is 4·2 Watts. In these two cases the energy expended is almost the same, but the longer filament of the ten volt lamp gives the most light, and the cells last longer.

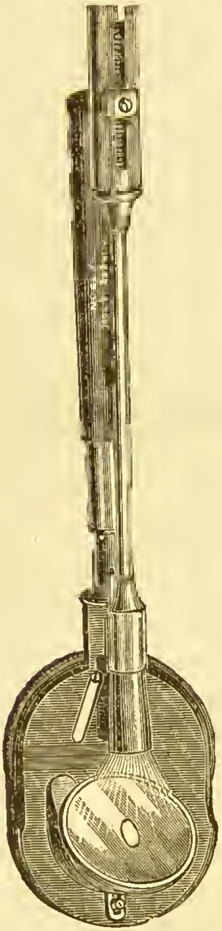

Fig. 98.—Ophthalmoscope, with electric lamp.

283. **Batteries for incandescent lamps.**—There

are four forms of battery in use for lighting small lamps:—1. Bichromate cells. 2. Dry batteries. 3. Chloride of silver cells. 4. Accumulators. Of these the bichromate cells are the least convenient for reasons already given (§§ 103, 279). Until lately, however, they have been used largely, but the other kinds of battery are much to be preferred. *Hellesen's* dry cell is very convenient and it is cheap. Six or eight dry cells of this make are fitted up in a plain oak box by *Mr. Schall* with a simple form of rheostat, and they may be trusted for a large number of examinations. It is wise in choosing a battery of this kind to have the cells as large as possible, that renewals may not be too frequently required. The chloride of silver cells are very light and convenient for small lamps, and would be the best were it not for their tendency to spoil after a time from local action. Sooner or later some of the silver chloride becomes dissolved in the exciting liquid, and is deposited as metallic silver on the surface of the zinc. Local action then takes place, and bubbles of hydrogen gas are evolved, the electromotive force of the battery becomes weakened, and the cells are often burst from the pressure of the gas.

If accumulators are used, small ones may be had for the sake of portability. Small accumulators are put up by several electrical firms for lighting the fairy lamps worn upon the stage, and these will serve very well for surgical lamps. The small sizes naturally require recharging more often than the large ones, but this is not an objection, because all accumulators are better for being recharged once every two or three months, and the capacity of the small cells is sufficient for lighting a cystoscope or similar lamp for about twenty hours. This will allow of the use of the lamp for an hour and a half per week for three months, which is quite as much as is likely to be required. If wished the small accumulators can be recharged at home from a few cells of any good primary battery.

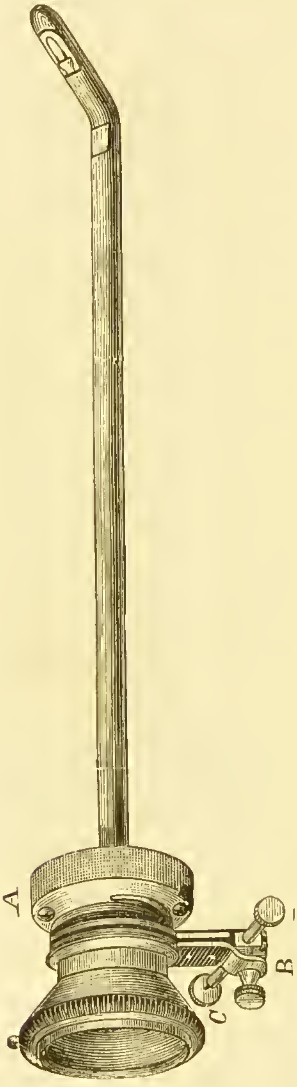

Fig. 99.—Cystoscope.

284. **Rheostats.** — We have already said that the lamps vary in their resistance very widely, and a variable resistance in the circuit is the most convenient method of compensating for these variations, without it some lamps would be over-heated and would quickly be destroyed. *Mr. Schall* arranges a rheostat of convenient size in the handle of his battery box. The resistance required for regulating the lamps need not be more than about six or eight ohms. As the current to be carried is only about half an ampère in a well made lamp the resistance is easily made of a few turns of fine german silver wire. Rheostats are equally important for cauteries, but there they have to carry large curents and must be made of thick wire; however, their total resistance need not be so great, for a variable resistance of half an ohm is sufficient to modify very greatly the current in a cautery circuit (§ 281).

285. **The cystoscope.**—This is an instrument for examining

the mucous membrane of the bladder, and it is perhaps the most important and useful of all the electric lamp instruments, because it affords information which cannot be obtained without it. The cystoscope (figs. 99, 100) consists of a beaked sound, in which

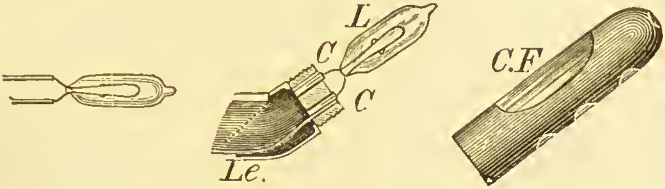

FIG. 100.—Arrangement of lamp in cystoscope.
L. Lamp. *CC*. Attachment to instrument. *CF*. Window in cap of instrument.

there is a telescopic arrangement by which the surface of the bladder is viewed through a small window of rock crystal. The lamp *L* is enclosed in the beak of the instrument and throws its light through another window, also of crystal, *CF* upon that part of the bladder wall which is in the field of view of the telescope. *B* is a screw for making contact, the wires are fastened at *CD*, fig. 99. For examining the upper part of the bladder a separate instrument with a small reflecting prism is used. A certain amount of practice is required to use the cystoscope properly, and to recognise the appearances of the mucous membrane of the bladder in health and in its various morbid conditions. With the dummy bladder (fig. 101) the necessary skill can be quickly picked up. For a full account of the instrument and mode of using it, see *Mr. Hurry Fenwick's* book on "the Electric Illumination of the Bladder and Urethra."[*] An anæsthetic is not absolutely necessary for a cystoscopic examination, but it is more convenient to employ one, though cocaine may be made to do at a pinch. The bladder must contain six or eight ounces of clear urine or clear water if a proper view of its walls is to be obtained.

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[*] London, *J. and A. Churchill*, 1888.

If the fluid present be even slightly turbid, the view is very much obscured; and if necessary the bladder must be washed out with warm boracic lotion until quite clear. If too little fluid be present in the bladder, the beak of the instrument with the lamp is likely to become buried in the folds of the mucous membrane, and there will be no light. Moreover, in that case the mucous membrane may be burned.

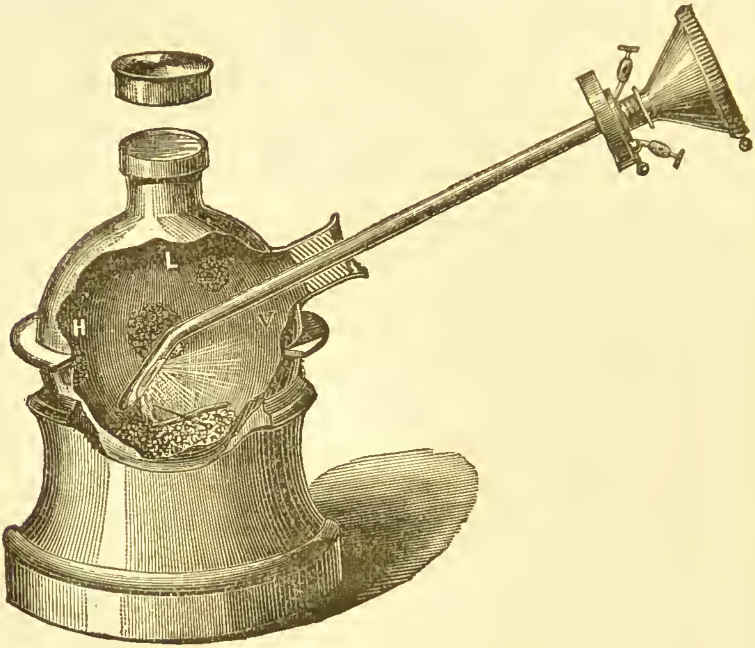

FIG. 101.—Cystoscope and dummy.

When the bladder contains eight ounces of clear fluid the end of the cystoscope lies free in the cavity, and the lamp is kept cool by the circulation of the water. The instrument must be pushed well home into the bladder and kept there; if it be allowed to work out at all, the beak may become engaged in the prostate, and then nothing will be seen and the prostate may be burned. The heat of the lamp is unimportant when it is surrounded by a volume of water, but when the lamp lies close against the mucous membrane there is no circulation of fluid round it, and it gradually grows hot and may burn if held too long in one place.

286. **The panelectroscope.**— Another universal lighting apparatus has been introduced by *Leiter*, of Vienna, under this name. It consists of a lantern with a handle and mirror, the light from a small incandescent lamp is projected by the mirror along a tube, which is inserted into the part to be examined. Tubes of various sizes are adapted to the instrument. It is especially useful for endoscopy of the urethra, but is also arranged for examining the ear, the pharynx, the stomach, &c. For a figure and description of the instrument, see *Mr. Hurry Fenwick's* account in the "British Medical Journal," 1881, part i., p. 462, and for a full account of the method of using it for examining the urethra, and of the appearances of the different morbid states, see his book already quoted in the last paragraph.

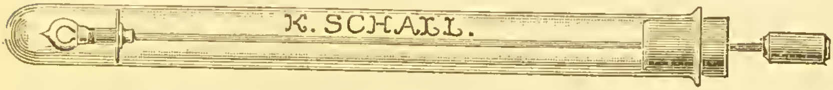

FIG. 102.—Lamp for abdominal surgery.

Another convenient lamp for abdominal surgery is shown in figure 102. It is designed in such a way as to be kept clean and aseptic without any difficulty. It may be left in the antiseptic solution until required for use. The attachment to the leads is by a double socket fitting, one wire making contact with the periphery of the tube which carries the lamp, and the other with an insulated lead passing down the centre. The enclosing tube of glass prevents any burning of the tissues with which it might come in contact during an operation.

287. **Use of electric light mains.**—When electric light mains are at hand, the current from them can be easily arranged to heat a cautery or light a small lamp. The current must not be led directly into the instruments because its electromotive force is so high that it would at once destroy small apparatus by overheating

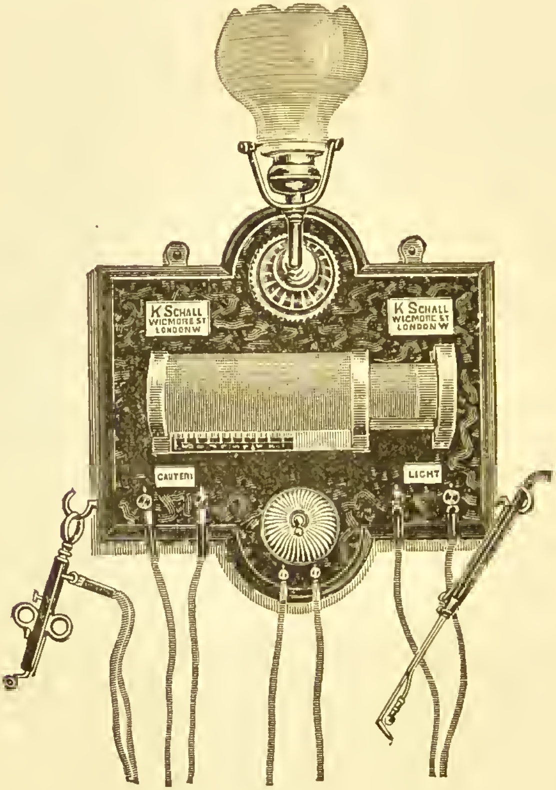

FIG. 103.—Mr. Woakes' transformer.

them. For the "continuous" current systems of lighting a suitable resistance must be interpolated, and for the "alternate" current a transformer must be employed. In the "Lancet" for August, 1891, a neat little transformer for surgical purposes was described by *Mr. Woakes* (fig. 103). Like a medical induction apparatus it consists of a fixed or primary coil in which the current from the main circulates, and of a sliding secondary coil, built up in three separate circuits. One of these gives a current suitable for a small surgical lamp, another is for heating cauteries, and the third is for producing an interrupted current suitable for faradization. The currents in all three parts are adjusted by sliding the secondary over the primary coil, and the winding of each circuit (number of turns and thickness of wire) is calculated for the electromotive force and current required for each purpose. A lamp in the primary circuit serves the double purpose of indicating when the current is turned on and off, and acts as a resistance apparatus to keep down the current in the primary circuit. The instrument is made by *Mr. Schall.* For use on the continuous current systems a good apparatus is made by *Messrs. Miller and Woods* of 34 Gray's Inn Road.

Recently a very complete little arc lamp has been introduced by *Messrs. Woodhouse and Rawson* under the name of the *Midget* lamp, which may prove a very useful source of light for surgeons, especially for the examination of the throat and nose, or for giving a general light during operations. It requires a current of five ampères at an E.M.F. of fifty volts, and therefore can only be used from the electric light mains. At present it is a novelty and has not been applied to surgical purposes, the light is said to be of 250 candle power.

288. **The electro-magnet.**—In certain cases this instrument is very valuable for the removal of fragments of iron or steel from the various parts of the body, especially from the eye. Permanent magnets can also be used. *Mr. Simeon Snell*[*] has made large use of the electro-magnet, and has had great success with it. If the particle of iron be very small, or if it be fixed at all firmly in the tissues a magnet is not likely to remove it. But if the piece of metal be larger, and if it be lying loose, as, for example, in the interior of the eye, it may be withdrawn most successfully by a magnet introduced through a small incision.

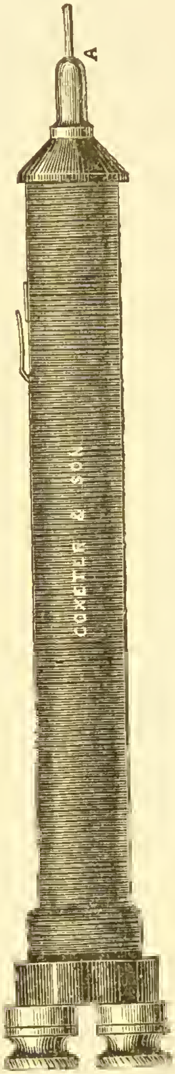

Fig. 104.—Electro-magnet.

One form of the instrument is figured here (fig. 104), several interchangeable pole pieces of different shapes and sizes are generally supplied, the most suitable one for each case can be screwed on at A as required. A few cells of any battery will suffice to excite the electro-magnet. It is sometimes useful to magnetise it by closing the current circuit after it has been placed in position near to the piece of iron. This is done in the instrument here figured by pressing down the small projecting slip of metal seen on the surface of the coils. The sudden magnetization then tends to jerk the piece of metal away from its bed. The vitreous humour will yield and allow the piece of iron to come forward to the magnet. In firmer tissues it is not always possible to extract it by an electro-magnet, for naturally it cannot hold the particle as firmly as it would be held by any kind of forceps. A large number of communications on the electro-magnet in surgery will be found in the medical journals.

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[*] "The Electro-magnet in Ophthalmic Surgery," and "Brit. Med. Journal," November, 1883.

Another use of magnetism in surgery is for the detection of buried pieces of iron or steel. For this purpose a freely suspended magnetic compass needle is used. When this is approached to a piece of iron or steel a deflection of the needle is produced.

There are many risks of fallacy in using a magnetic needle for the detection of pieces of iron. An iron bedstead, a steel truss worn by the patient or the operator, a pocket knife or other article of steel may act as a disturbing element, and if unsuspected may puzzle the operator hopelessly.

DESCRIPTION OF PLATES.

PLATES I.—VI.

The Motor Points.

PLATE.
I. THE HEAD AND NECK.
II. THE UPPER LIMB *(back).*
III. THE UPPER LIMB *(front).*
IV. THE THIGH *(front).*
V. THE THIGH AND LEG *(back).*
VI. THE LEG AND FOOT *(outer side).*

PLATES VII.—XI.

The Cutaneous Nerves.

VII. THE HEAD AND NECK.
VIII. THE UPPER LIMB *(back).*
IX. THE UPPER LIMB *(front).*
X. THE LOWER LIMB *(front).*
XI. THE LOWER LIMB *(back).*

PLATE I.

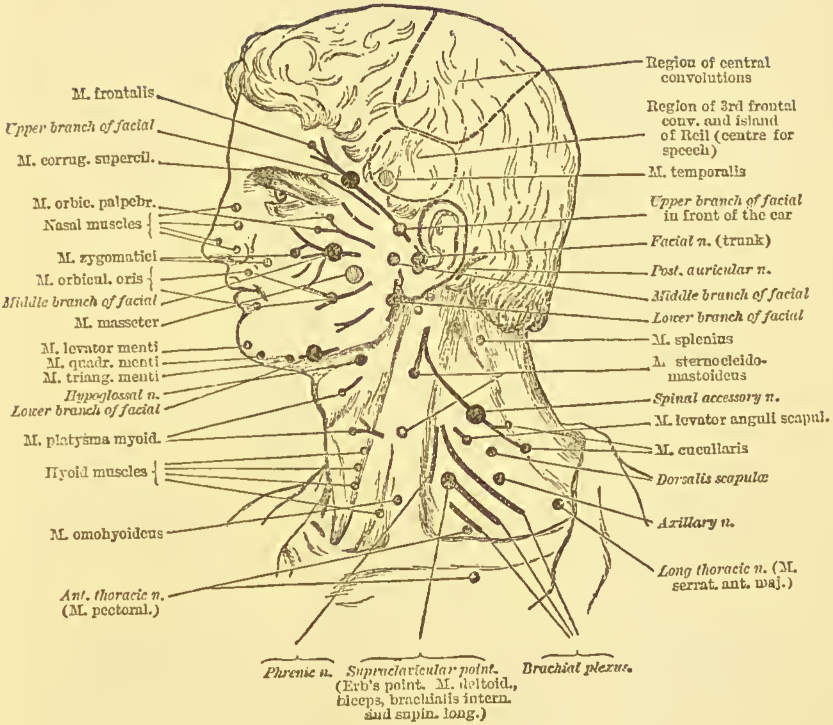

M. frontalis
Upper branch of facial
M. corrug. supercil.
M. orbic. palpebr.
Nasal muscles
M. zygomatici
M. orbicul. oris
Middle branch of facial
M. masseter
M. levator menti
M. quadr. menti
M. triang. menti
Hypoglossal n.
Lower branch of facial
M. platysma myoid.
Hyoid muscles
M. omohyoideus
Ant. thoracic n. (M. pectoral.)
Region of central convolutions
Region of 3rd frontal conv. and island of Reil (centre for speech)
M. temporalis
Upper branch of facial in front of the ear
Facial n. (trunk)
Post. auricular n.
Middle branch of facial
Lower branch of facial
M. splenius
M. sternocleido-mastoideus
Spinal accessory n.
M. levator anguli scapul.
M. cucullaris
Dorsalis scapulæ
Axillary n.
Long thoracic n. (M. serrat. ant. maj.)
Phrenic n.
Supraclavicular point. (Erb's point. M. deltoid., biceps, brachialis intern. and supin. long.)
Brachial plexus.

PLATE II.

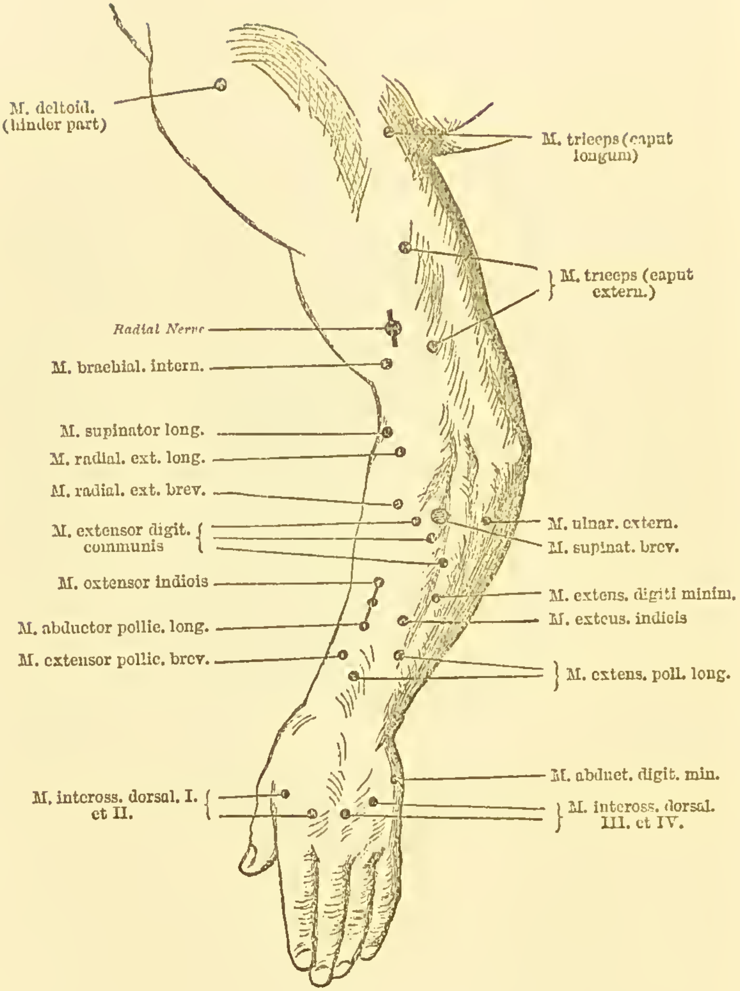

M. deltoid. (hinder part)
M. triceps (caput longum)
M. triceps (caput extern.)
Radial Nerve
M. brachial. intern.
M. supinator long.
M. radial. ext. long.
M. radial. ext. brev.
M. extensor digit. communis
M. ulnar. extern.
M. supinat. brev.
M. extensor indicis
M. extens. digiti minim.
M. abductor pollic. long.
M. extens. indicis
M. extensor pollic. brev.
M. extens. poll. long.
M. abduct. digit. min.
M. inteross. dorsal. I. et II.
M. inteross. dorsal. III. et IV.

PLATE III

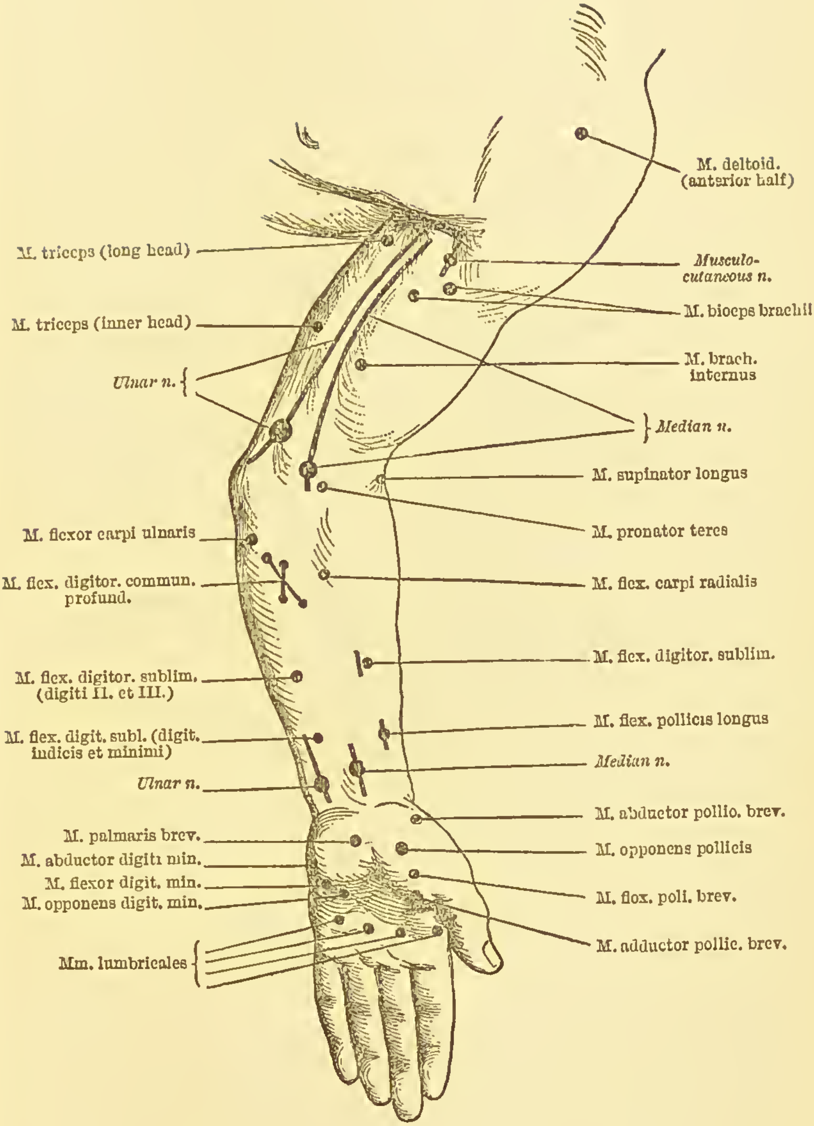

M. deltoid. (anterior half)
M. triceps (long head)
Musculo-cutaneous n.
M. biceps brachii
M. triceps (inner head)
M. brach. internus
Ulnar n.
Median n.
M. supinator longus
M. pronator teres
M. flexor carpi ulnaris
M. flex. digitor. commun. profund.
M. flex. carpi radialis
M. flex. digitor. sublim.
M. flex. digitor. sublim. (digiti II. et III.)
M. flex. pollicis longus
M. flex. digit. subl. (digit. indicis et minimi)
Median n.
Ulnar n.
M. abductor pollic. brev.
M. palmaris brev.
M. opponens pollicis
M. abductor digiti min.
M. flexor digit. min.
M. flex. poli. brev.
M. opponens digit. min.
M. adductor pollic. brev.
Mm. lumbricales

PLATE IV

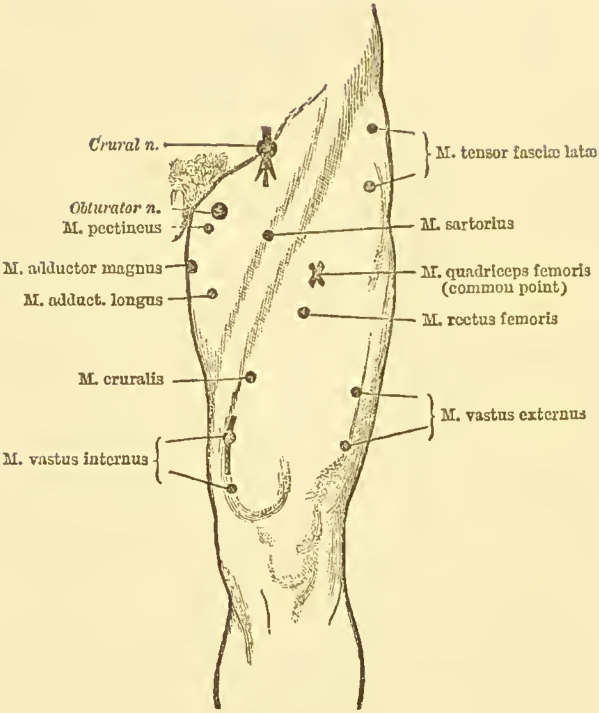
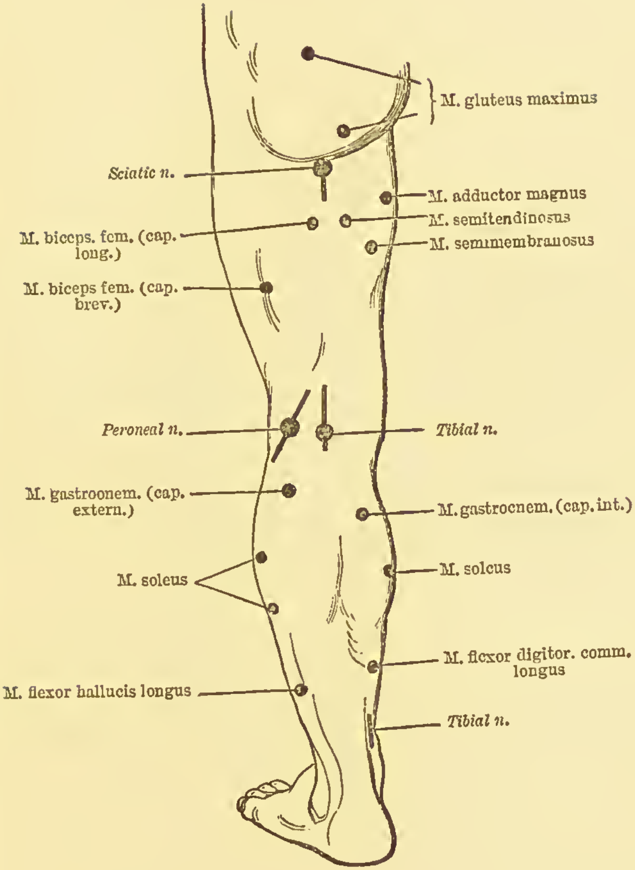

Crural n.
Obturator n.
M. pectineus
M. adductor magnus
M. adduct. longus
M. cruralis
M. vastus internus
M. tensor fasciæ latæ
M. sartorius
M. quadriceps femoris (common point)
M. rectus femoris
M. vastus externus

PLATE V


M. gluteus maximus
Sciatic n.
M. adductor magnus
M. semitendinosus
M. biceps. fem. (cap. long.)
M. semimembranosus
M. biceps fem. (cap. brev.)
Peroneal n.
Tibial n.
M. gastrocnem. (cap. extern.)
M. gastrocnem. (cap. int.)
M. soleus
M. soleus
M. flexor digitor. comm. longus
M. flexor hallucis longus
Tibial n.

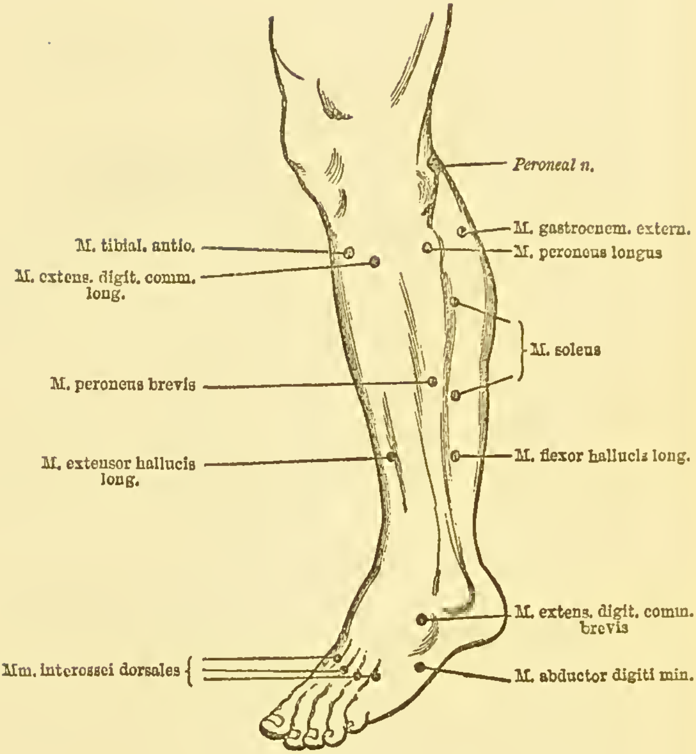
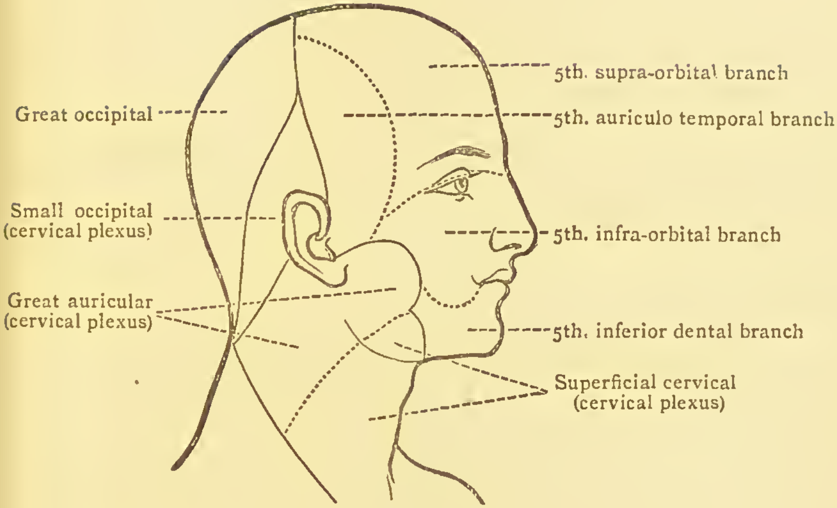

Peroneal n.
M. gastrocnem. extern.
M. tibial. antic.
M. peroneus longus
M. extens. digit. comm. long.
M. soleus
M. peroneus brevis
M. extensor hallucis long.
M. flexor hallucis long.
M. extens. digit. comm. brevis
Mm. interossei dorsales
M. abductor digiti min.

PLATE VII.


5th. supra-orbital branch
Great occipital
5th. auriculo temporal branch
Small occipital (cervical plexus)
5th. infra-orbital branch
Great auricular (cervical plexus)
5th. inferior dental branch
Superficial cervical (cervical plexus)

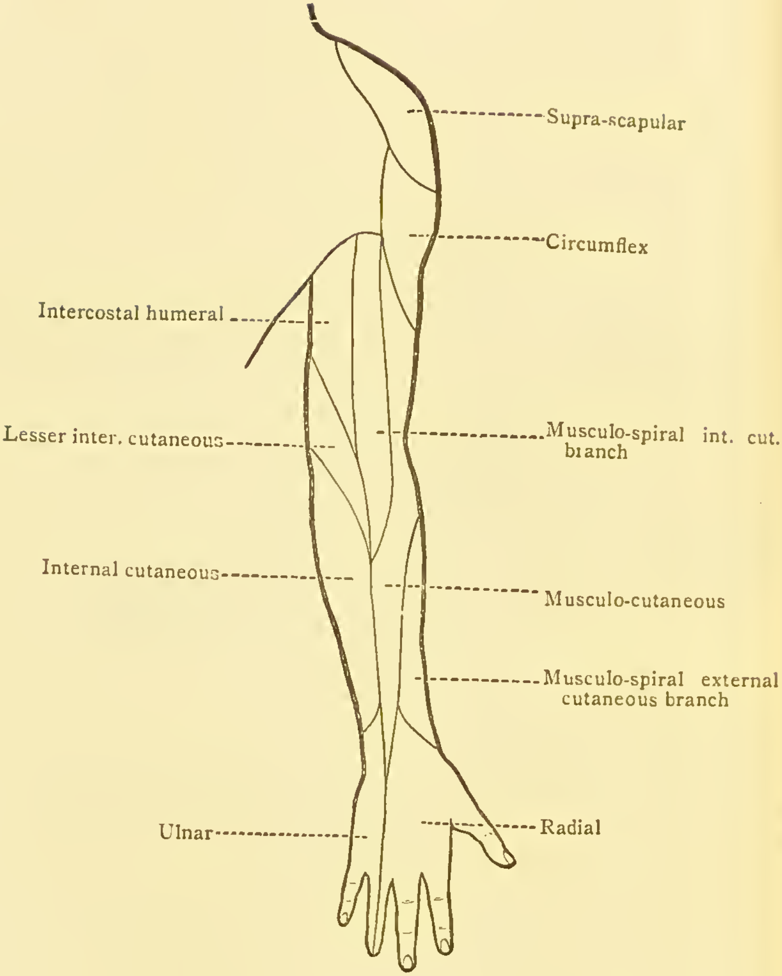

Supra-scapular
Circumflex
Intercostal humeral
Lesser inter. cutaneous
Musculo-spiral int. cut. branch
Internal cutaneous
Musculo-cutaneous
Musculo-spiral external cutaneous branch
Ulnar
Radial

PLATE IX.

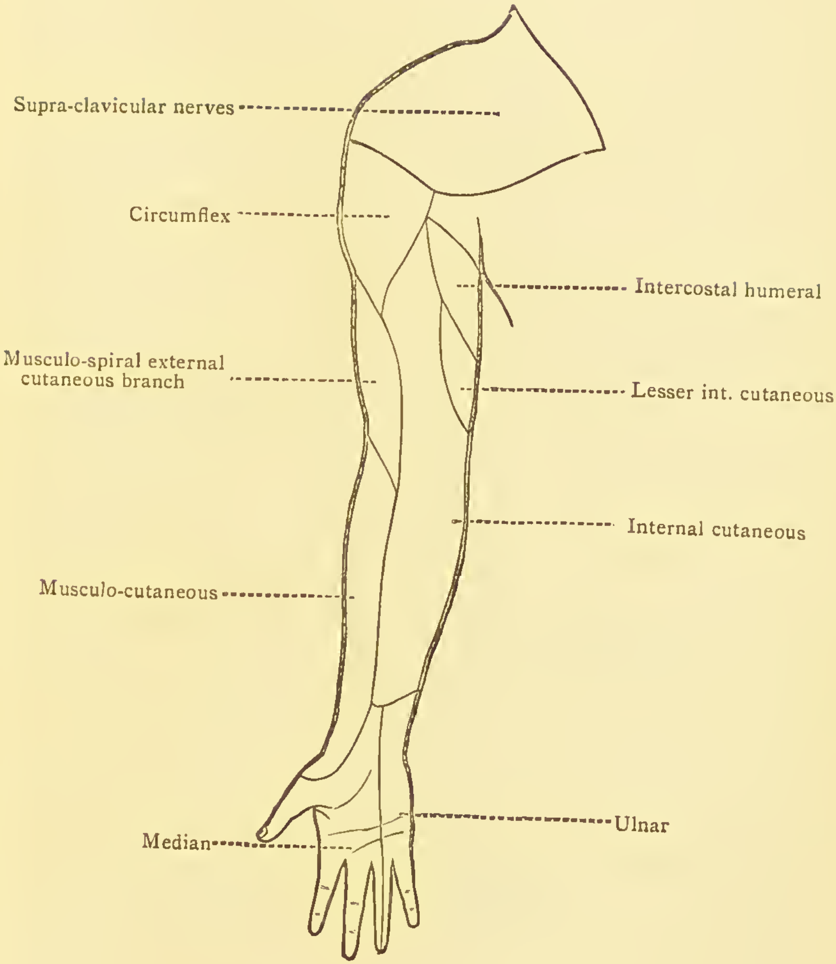

Supra-clavicular nerves
Circumflex
Intercostal humeral
Musculo-spiral external cutaneous branch
Lesser int. cutaneous
Internal cutaneous
Musculo-cutaneous
Ulnar
Median

PLATE X.

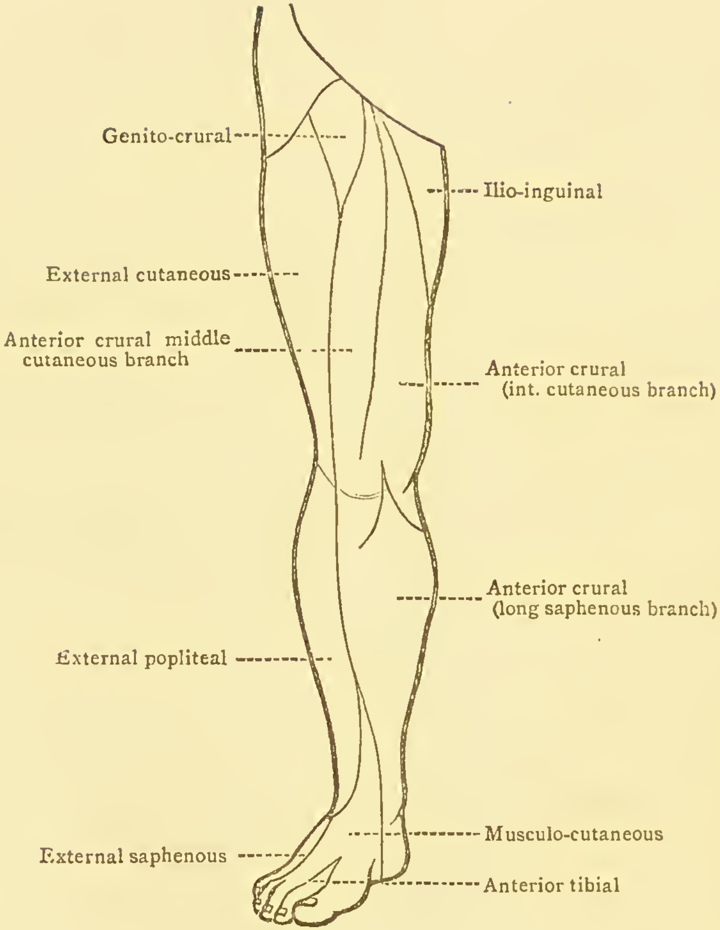
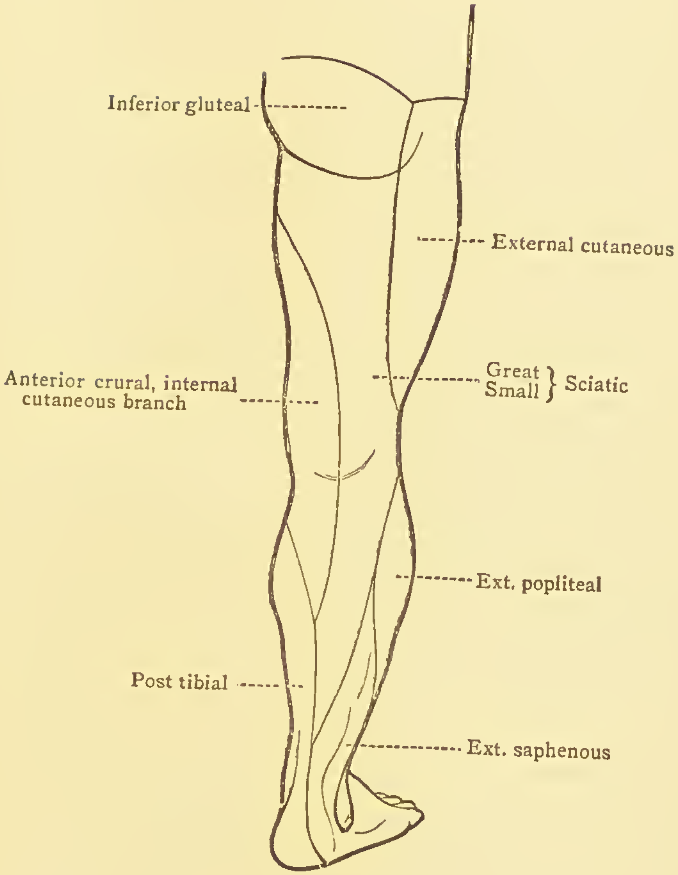

Genito-crural
Ilio-inguinal
External cutaneous
Anterior crural middle cutaneous branch
Anterior crural (int. cutaneous branch)
Anterior crural (long saphenous branch)
External popliteal
Musculo-cutaneous
External saphenous
Anterior tibial

PLATE XI.


Inferior gluteal
External cutaneous
Anterior crural, internal cutaneous branch
Great
Small
Sciatic
Ext. popliteal
Post tibial
Ext. saphenous

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